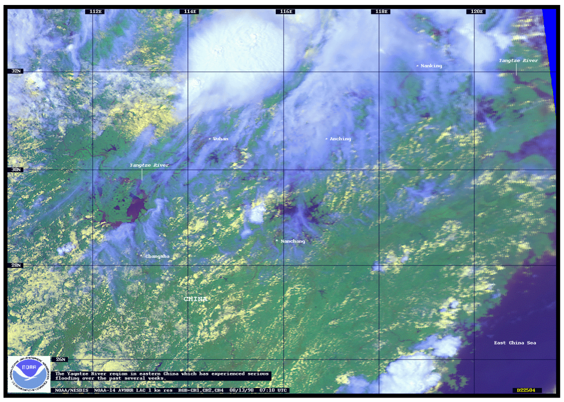
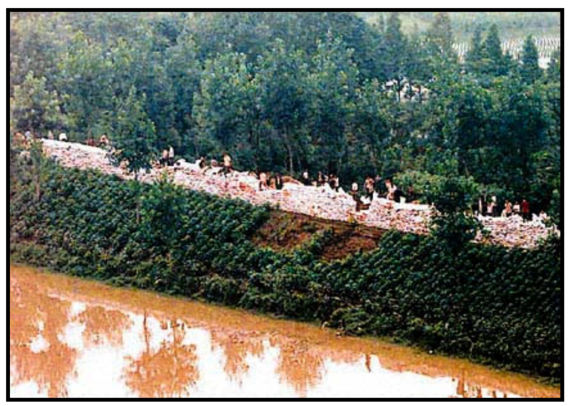
A Technical Report of Project (GT/1010-00-04):

Early Warning, Forecasting and Operational Flood Risk Monitoring in Asia (Bangladesh, China and India)





UNEP-Division of Early Warning & Assessment

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Preface

Floods are one of the most common natural disasters throughout the globe. Due to high population density along rivers especially in Asian countries such as Bangladesh, China and India, floods cause huge losses of lives and property every year. It is proposed to develop an operational flood risk monitoring system for flood-affected developing countries using various factors leading to floods. Through this project, numerous parameters will be brought together into a Geographic Information System (GIS) for selected pilot river basins in the Asian region. This will demonstrate to countries affected by floods the usefulness of GIS systems to visualize the onset of floods, the probability of floods and how floods affect areas. The output of the proposed work would be used by UNEP in providing advisory services based on sound scientific methods related to early warning systems suitable for developing countries to avoid enormous damages caused by frequent floods.

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Main Findings

- A number of techniques and models related to the early warning and forecasting of floods have been developed by many scientists and various organizations.
- From 1960 to 1999, floods accounted for about one third of all natural catastrophes, caused more than half of all fatalities, and were responsible for a third of overall economic losses.
- Less than half of all flood disasters occurred in Asia; however, over 80% of the people killed, affected or homeless were located in this continent.
- There are on average 509 people/km^2 in the Yangtze Basin and 999 people/km^2 in Ganges/Brahmaputra Basin, compared to 137 people/km^2 in China and 367 people/km^2 in India and Bangladesh.
- About 500 million people, 50% of the population in India and Bangladesh, and about 300 million people, or about 25% of the population of China, live within these two basins.
- The population in these three countries has increased from 954 million to 2,411 million in the last 50 years.
- In the Ganges basin, 60.2% of the area is under high population pressure. In the Yangtze basin, 60% of the area is under high population pressure.
- In the Ganges/Brahmaputra basin, about 6.5% of the land has been accorded some sort of formal protection.
- In the Yangtze basin, about 7.8% of the land has been accorded some sort of formal protection. Forests, especially tropical and sub-tropical forests are biologically the most diverse lands and home to thousands of endemic species.
- Worldwide, 29.8% of the Ganges/Brahmaputra basin and 15.1% of the Yangtze basin are “bright hot” in the progress of economic development in the countries of India, China and Bangladesh; at the same time, they are “hotspots" for biodiversity.
- Of the 25 total hotspots around the world, 2 lie partially within the Yangtze basin. The mountains of south central China are mostly located in the Yangtze basin and part of the Indo-Burma hotspot lies within the Yangtze basin. The Indo-Burma hotspot is largely located in the Ganges/Brahmaputra basin.
- Population pressure is high in the portions of the hotspots that lie in the two basins, with 27.5 million people at risk in high-density areas.
- Extensive use of these two basins for human activity has led to conflicts between resource use and environmental quality in these areas.
- Environmental vulnerability is recognized due to recent advances in spatial information technologies which show that physical changes in the environment, increasing storm activity, floods and unusual weather patterns have some links to global climate change.
- The human impact on the environment increases environmental vulnerability, hopefully increasing human awareness and stimulating human efforts to protect the environment.

Table of contents

List of figures and tables

Figures

Tables

1 Introduction

Large river floodplains around the world support heavy population settlements, where development goals are most often improved navigation, enhanced agricultural production and flood protection. Floods are one of the most common devastating natural hazards in the world, claiming more lives and property than any other natural disaster. Floods are frequent and a common feature of every year, especially after heavy rains, heavy thunderstorms, winter snow thaws, strong cyclones, and monsoons. Floods can be slow or fast rising depending upon the amount of rains and snow melt, and generally develop over a period of days. Dam failures due to floods are potentially the worst events, often caused by poor design or structural damage due to a major event such as an earthquake.

Flood disasters account for about a third of all natural disasters throughout the world and are responsible for more than half of the fatalities (Berz, 2000). The trend analyses reveal that major flood disasters and the losses generated by them have increased drastically in recent years. There is a distinct increase with respect to economic losses and the rising numbers of events that attracts the attention of international agencies. Flood losses in the U.S. now exceed US $5 billion in individual years (NOAA, 1994). Flood damage was estimated between US $350-400 million per year in Australia (Smith and Word, 1998). In the last 10 years, losses amounting to more than US $250 billion have been borne by societies all over the world to compensate for the consequences of floods (Berz, 2000). Flooding in countries like Bangladesh, China and India is frequent enough to be considered an annual event.

People all over the world have learned to live with floods. However, the population sometimes is taken completely by surprise when a river or the sea rises to an unacceptable level. In this context, three aspects are very important: (i) the dramatic increase in the world's population which creates the necessity to settle in risk prone areas; (ii) the migration of refugees to an unfamiliar environment; and (iii) increased population mobility and the desire of people to live in areas with a good natural environment and certain climate. All these factors bring people into areas whose natural features they do not know. They are not aware of what can happen and they have no idea how to behave if nature strikes. Even if people have experienced a disaster themselves, they tend to forget its lessons within a few years (Berz, 2000).

Economically, floods are a leading cause of losses from natural events. One flood is not only a single disaster event, but creates a cumulative loss from related small and medium sized events. The money spent worldwide on flood control (dykes, reservoirs, barrage, etc.) is far greater than that spent on protection against other impacts from nature.

A comparison of flooding and all other natural hazards in long-term analyses (1988-97) reveals that (Berz, 2000):

- Floods account for about a third of all natural catastrophes.
- Floods cause more than half of all fatalities.
- Floods are responsible for a third of the overall economic loss.
- Floods' share in insured losses is relatively small, with an average of less than 10%.

A flood is defined as any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream. When a bank overflows, the water spreads over the flood plain and generally becomes a hazard to society. Floods are by and large a function of location, intensity, volume and duration of precipitation. Floods are caused by excessive rainfall, snowmelt or dam failure. The rivers generally originate from mountains. Excessive rainfall or snowmelt in mountainous regions results in flooded rivers. Mountainous regions become more vulnerable to landslides, hyperconcentrated flows, debris flows, etc. (Scofield and Morgottini, 1999). In developing countries such as India, China, Bangladesh, Indonesia and Vietnam, due to water scarcity, large populations live along the major rivers and as a result the floods are more devastating, killing millions of people and damaging property every few years.

Fig. 1-1 Flood tracks: A train brimming with passengers move through floodwaters on September 9, 1998 at Arikhola, 40 kilometers from Dhaka (Source: AFP, 1998)

This study presents an overview of operational flood risk monitoring, early warning and forecasting in Asia (Bangladesh, China and India), with a focus on the Ganges/Brahmaputra and Yangtze River basins. The report looks at the flood situation in each basin in a regional context, and recommends future directions to develop an operational flood risk monitoring system for flood-affected developing countries. Through this project, numerous parameters have been brought together into a Geographic Information System (GIS) for selected pilot river basins in the Asian region. This demonstrates the usefulness of GIS systems to visualize the onset of floods, chances of floods and prediction of flood-affected areas. The output of the proposed work could be used by the United Nations Environment Programme (UNEP) to provide advisory services based on sound scientific methods related to early warning systems suitable for developing countries to avoid enormous damages caused by frequent floods.

The main objectives of this study are:

- To review early warning and flood forecasting tools and models being used by developed countries and assess the gap in knowledge and technology being deployed by developing countries. This should assist in knowledge transfer related to operational systems for flood risk monitoring using the latest tools and technologies.
- To compile and analyze relevant databases on numerous parameters using a Geographic Information System (GIS) for the two river basins to demonstrate the usefulness of GIS in visualizing the early warning of floods, occurrence of floods, and total affected areas.
- To assess human vulnerability to, and coping capacity for, environmental threats in the two basins using population pressure, land cover, topographical characteristics of the landscape, and the probability of natural hazards (flood).

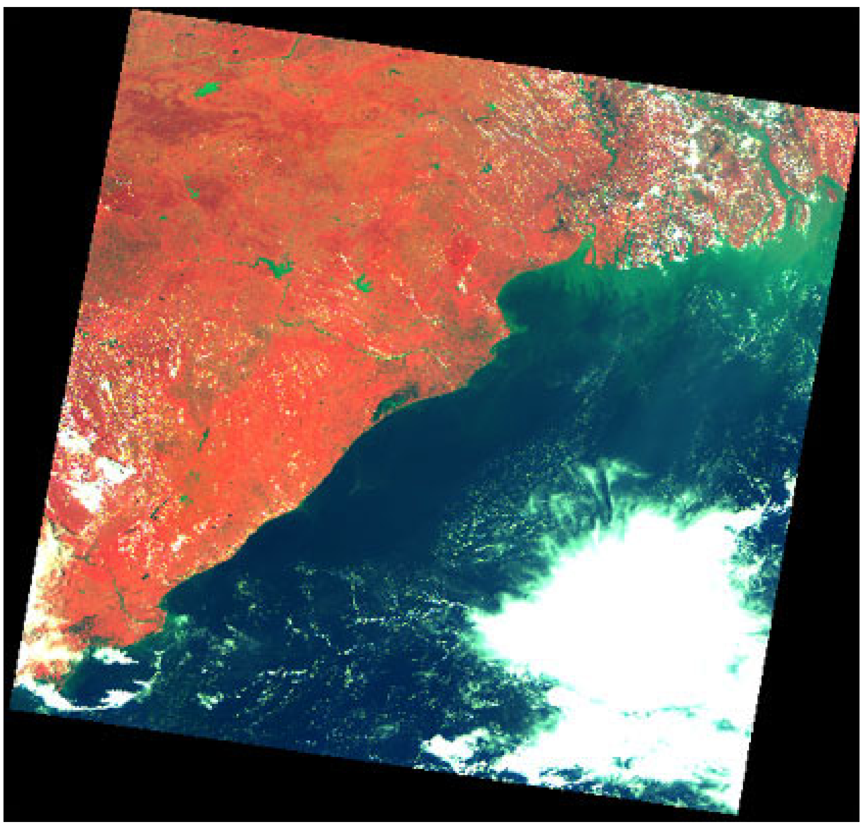

Fig.1-2 Image: Cyclone in India (Source: NNRMS Bulletin-24, 2000, Department of Space, India)

2 About floods

Of all the natural hazards capable of producing a disaster, a flood is by far the most common in causing loss of life, human suffering, inconvenience and widespread damage to buildings, structures, crops and infrastructure. Floods can disrupt personal, economic, and social activities and set back a nation's security and development by destroying roads, buildings and other assets.

Flooding is a natural feature of drainage systems and rivers and streams. When drainage channels are filled and rivers and streams can no longer accommodate excessive water generated by severe weather conditions, the channels overflow their natural or artificial banks and water enters the surrounding lands causing flooding.

Severe weather conditions which lead to intense rainfall, such as thunderstorms, cold fronts, tropical waves, tropical depressions, tropical storms and hurricanes can lead to flooding.

2.1 The definitions

Floods are physical events and natural hazards. Floods can be slow or fast rising depending upon the amount of rains and snow melt, generally developing over a period of days.

Fig. 2.1-1 Flood in Bangladesh; the photo was taken in Bangladesh's Satkhira Province during the early days of flooding in October 1998 (Source: FHI, 1998)

A number of definitions related to floods have been proposed by various organizations and many scientists. Some of these definitions are summarized below.

A flood is defined as "any relatively high water flow that overtops the natural or artificial banks in any portion of a river or stream." When a bank overflows; the water spreads over the flood plain and generally becomes a hazard to society. Floods are caused by excessive rainfall, snowmelt or dam failure. The rivers generally originate from mountains. Excessive rainfall or snowmelt in mountainous regions results in flooded rivers. Mountainous regions become more vulnerable to landslides, hyperconcentrated flows, debris flows, etc. (Scofield and Morgottini, 1999).

Smith and Word (1998) have pointed out that the terms 'floods', 'flooding' and 'flood hazard' cover a very wide range of phenomena, not all of which are treated with equal emphasis …… The main focus in this project is on river floods, with low-lying deltas and estuaries of many of the world's major rivers exposed to the hazards of flooding from the sea by storm surges and tsunami, as is all low-lying coastal land.

For present purposes, a meaningful definition of a flood should not only incorporate the notions of inundation and damage, but also move beyond the restrictive definitions of river floods given. A flood is an overflowing of water from rivers onto land. Floods also occur when water levels of lakes, ponds, aquifers and estuaries exceed some critical value and inundate the adjacent land, or when the sea surges on coastal lands much above the average sea level. Nevertheless, floods are a natural phenomenon important to the life cycle of many biotas, not the least of which is mankind. Floods became a problem as humans began establishing farms and cities in the bottomlands of streams and rivers. In doing so, they not only expose their lives and properties to the ravages of floods, but also exacerbate floods by paving the soil and constructing stream channels. Over time, continued urbanization of natural floodplains has caused great annual losses of both wealth and human life. In this way, in many countries and regions of the world, floods are the most deadly hazards in terms of both loss of human lives and material damage (Fattorelli et al., 1999).

2.2 Flood as hazards

2.2.1 Flooding as a natural hazard

Most of the natural hazards result from the potential for extreme geophysical events, such as floods, to create an unexpected threat to human life and property (Smith, 1996). When severe floods occur in areas occupied by humans, they can create natural disasters that involve the loss of human life and property plus serious disruption to the ongoing activities of large urban and rural communities. Although the terms 'natural hazards' and 'natural disasters' emphasize the role of the geographical processes involved, these extreme events are increasingly recognized primarily as the 'triggers' of disaster, which often have more complex origins including many social and economic factors.

A flood in a remote, unpopulated region is an extreme physical event of interest only to hydrologists. Entirely natural floodplains can be drastically changed – but not damaged – by the events that create them. Indeed, most floodplain ecosystems are geared to periodic inundation. Terms such as flood risk and flood losses are, therefore, essentially human interpretations of the negative economic and social consequences of natural events. As with other human value judgments, different groups of people have been found to differ markedly in their selection and definition of the risks from flooding (Green et al., 1991). In addition, the flood risk in any given locality may be increased by human activity, such as unwise land-use practices related to flood control structures or by ineffective emergency planning. The real risk from floods stems from the likelihood that a major hazardous event will occur unexpectedly and that it will impact negatively on people and their welfare.

Fig. 2.2-1 Flood in Bangladesh. (Source: FHI, 1998)

Flood hazards result from a combination of physical exposure and human vulnerability reflected by key social-economic factors such as the number of people at risk in the floodplain or low-lying coastal zone, the extent of flood, and the ability of the population to anticipate and cope with hazard. It is the balance between these two elements, rather than the physical event itself, which defines natural hazard and determines the outcome of a natural disaster. In Fig. 2.2-2 Smith and Ward (1998) show variations of river stages through time in relation to the band of social and economic tolerance available at a hypothetical location. As long as the river flows close to the average or expected level, there is no hazard and the discharge is perceived as a resource because it supplies water for useful purposes, such as irrigation or water transport. However, when the river flow exceeds some predetermined threshold of local significance and extends outside the band of tolerance, it will cease to be beneficial and becomes hazardous. Thus, very low or very high flows will be considered to create a drought or a flood hazard, respectively.

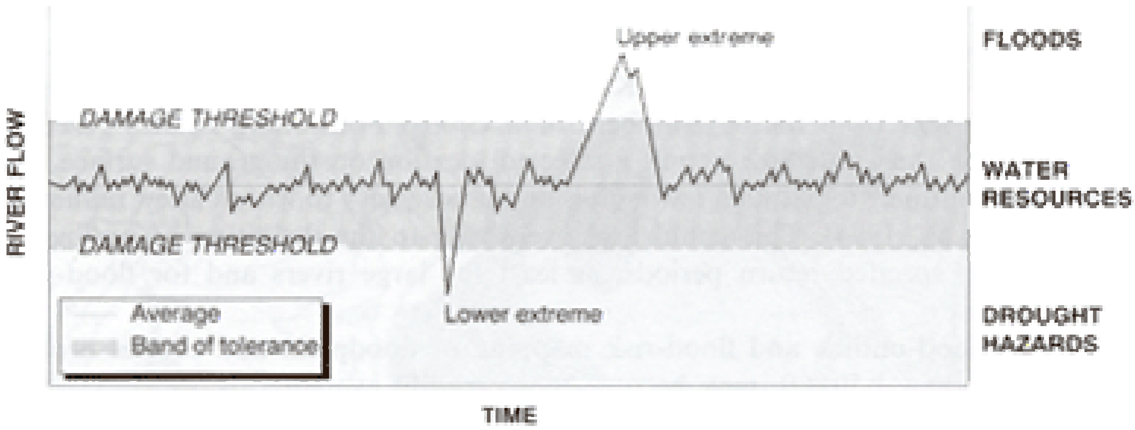

Fig. 2.2-2 Sensitivity to flood hazard expressed in relation to the variability of river discharge and the degree of socio-economic tolerance at a site (Source: Modified from Hewitt and Burton, 1971)

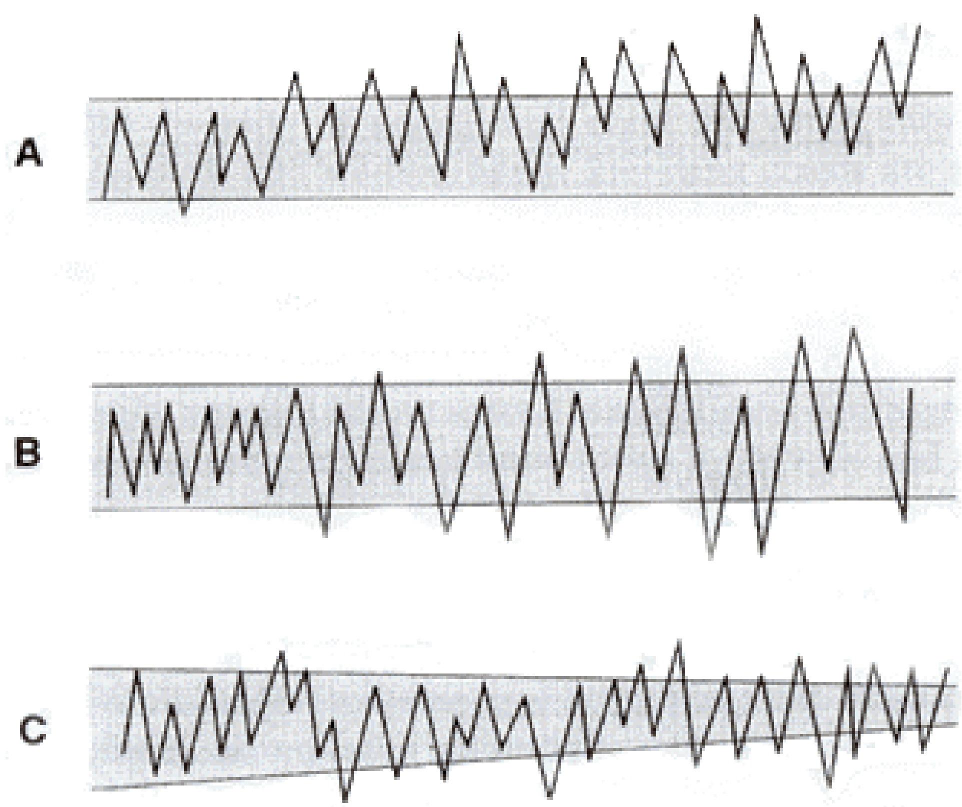

Fig. 2.2-3 A schematic illustration of increases in human vulnerability to flood hazard caused by changes in the distribution of flood events and decrease in socio-economic tolerance at a site (Source: After De Vries, 1985, and Smith and Ward, 1998)

The relationship between physical exposure and human vulnerability is highly dynamic and can change through time. Fig. 2.2-3 shows various possibilities giving rise to increased flood risk. Fig. 2.2-3 (A) represents the effect of a constant band of socioeconomic tolerance and constant variability of flows but a trend to higher mean values leading to more frequent breaches of the tolerance threshold, perhaps due to channel constructions which limit the capacity of the river banks to contain specified flood flows. Fig. 2.2-3 (B) represents a constant band of tolerance and constant mean value of flow but an enhanced risk arising from increased variability of flows. This might be due to a shift in climate leading to more intense rainstorms. In fig. 2.2-3 (C) the flow regime of the river does not change but the socio-economic band of tolerance narrows, perhaps because of floodplain invasion placing more people and property at risk (Smith and Ward, 1998).

Another important attribute of flood risk is the relative unpredictability of the event. The difficulty of issuing precise warnings of flood locations and their timing is a major cause of flood disaster, especially with flash floods. On the other hand, many rivers exhibit regular floods that, especially in large drainage basins, will rise slowly and predictably in seasonal 'flood pulse', thereby offering an opportunity for an efficient loss-reducing response.

2.2.2 Global patterns and trends

Flooding along low-lying plains adjacent to rivers and coasts is commonly regarded as the most frequent and widespread natural hazard in the world. Floods regularly account for about one-third of all global disasters arising from geophysical hazards and adversely affect more people than any other natural hazard, apart from drought. This dominance is usually explained by the fact that the overtopping of natural or artificial boundaries of a watercourse, together with the submergence of coastal zones, is a frequent occurrence compared with the incidence of other hazards such as damaging earthquakes or major volcanic eruptions. In addition, the density of much floodplain and coastal settlement places large numbers of people at risk.

Any estimate of a flood hazard is plagued by the problem of defining basic terms (e.g. 'flood disaster' or 'flood-prone') and the related inadequacy of recorded data on flood events and losses. In the absence of any agreed international database of flood disasters, it is difficult to authenticate claims about flood losses worldwide and any related trends.

Area	Events	Deaths	Affected	Homeless	Damage
Africa	16.0	4.5	1.0	5.1	1.9
Asia	41.1	82.2	95.3	85.1	65.6
C. America	7.1	1.7	0.1	0.5	1.3
Caribbean	3.2	1.2	0.3	0.2	0.2
Europe	8.7	2.1	0.6	0.5	20.1
Near East	4.1	1.5	0.2	1.0	0.7
Pacific	1.2	0.1	0.0	0.0	0.2
S. America	18.6	6.7	2.5	7.6	10.0
Totals	100.0	100.0	100.0	100.0	100.0

Table 2.2-1 Percentage of all recorded flood disasters and associated flood impacts 1964-96 by continental area (excluding USA) (Source: OFDA, 1996 and Smith, 1998)

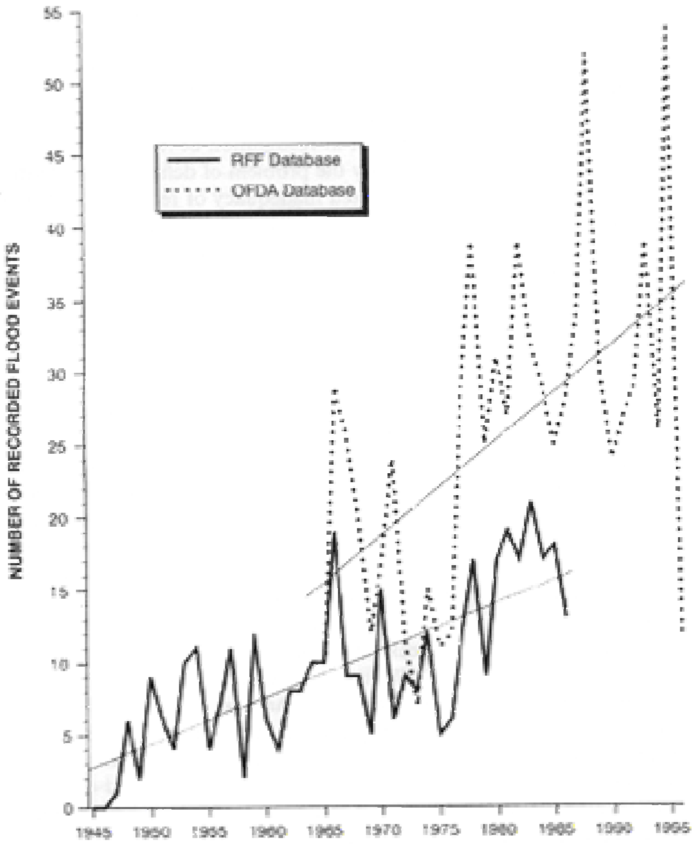

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Fig. 2.2-4 The increase in recorded flood disasters throughout the world (Source: Data from Glickman et al., 1992, and OFDA, 1996)

Because of differing definitions and more general reporting difficulties, all the resulting figures should be treated with caution. According to Gleckman et al. (1992), floods are responsible for 31% of the natural disasters that claimed 25 or more lives worldwide between 1945 and 1986. These data also show that, between 1945 and 1986, the average annual numbers of floods causing 25 or more deaths have more than tripled, a trend that is confirmed by the OFDA series from 1964 to 1996 (Fig. 2.2-4). The OFDA figures indicate that, since 1964, 835 floods that occurred outside the USA have killed over 130,000 people, rendered about 70 million homeless and adversely affected well over one billion humans. The direct economic cost of such flood disasters is estimated at over US $91 billion. The burden of flood disasters is most heavily borne by the impoverished countries of Asia. Table 2.2-1 shows that, while less than half of all flood disasters occurred in Asia, over 80% of people killed, affected or made homeless are located in this continent. Table 2.2-2 shows the total number of people reported killed by continent and by type of phenomenon.

	Oceania	US and Canada	Rest of Americas	Europe	Africa	Asia	Total
Slides	279	-	2010	644	225	5,500	8,658
Droughts	98	0	-	-	12	2,680	2,790
Earthquakes	70	63	3,456	2,395	816	91,878	98,678
Epidemics	115	138	11,985	411	57,082	14,316	84,047
Extremes temperatures	27	1,218	780	954	102	5,974	9,055
Floods	30	363	35,235	2,839	9,487	55,916	103,870
Wild Fires	8	41	60	127	79	260	575
Wind Storms	262	1,718	11,546	913	1,612	185,739	201,790
Volcanoes	9	-	77	-	-	994	1,080
Other Natural Disasters*	2,182	-	15	-	-	489	2,686
Non-Natural Disasters**	534	-	12,353	7,832	16,136	42,453	79,308
TOTAL	**3,614**	**3,541**	**77,517**	**16,115**	**85,551**	**406,199**	**592,537**

Table 2.2-2 Total number of people reported killed, by continent and by type of phenomenon (1990-1999) (Source: IFRC World Disaster Report 2000. *Insect Infestation, Wave/Surge, **Industrial, Transport and Misc accidents)

2.3 Type of floods

Among the many classifications of floods, Smith and Ward (1998) classified floods as river floods and coastal floods.

2.3.1 River floods

- Floods in river valleys occur mostly on floodplains or wash lands as a result of flow exceeding the capacity of the stream channels and over spilling the natural banks or artificial embankments.
- Sometimes inundation of the floodplain, or of other flat areas, occurs in wet conditions when an already shallow water table rises above the level of the ground surface. This type of water table flooding is often an immediate precursor of overspill flooding from the stream channels.
- In very dry conditions, when the ground surface is baked hard or becomes crusted, extensive flat areas may be flooded by heavy rainfall pounding on the surface. This rainwater flooding is typical of arid and semi-arid environments.
- Sheet wash flooding occurs by the unimpeded lateral spread of water moving down a previously dry or nearly dry valley bottom or alluvial fan. This is typical of arid and semi-arid areas where no clearly defined channels exist.
- In urban areas, flooding often results from over spilling or surface pounding, as described above, but may also occur when urban storm water drains become supercharged and overflow (Smith and Ward, 1998).

2.3.2 Coastal floods

- Floods in low-lying coastal areas, including estuaries and deltas, involve the inundation of land by brackish or saline water. Brackish-water floods result when river water overspills embankments in coastal reaches as normal flow into the sea is impeded by storm-surge conditions, or when large freshwater flood flows are moving down an estuary.
- Direct inundation by saline water floods may occur when exceptionally large wind-generated waves are driven into semi-enclosed bays during severe storm or storm-surge conditions, or when so-called ‘tidal waves’, generated by tectonic activity, move into shallow coastal waters.

2.3.3 Other flood types from a different perspective

Flash floods

These floods are frequently associated with violent, convection storms of a short duration. Flash flooding can occur in almost any area, but is most common in mountain districts subject to frequent severe thunderstorms. Flash floods are often the result of heavy rains of short duration falling over a small area. This particular type of flooding has been known to wash away roads and bridges, damage houses and drown livestock.

Riverine floods

A riverine flood occurs in the valley of a large river with many tributaries. Usually flooding develops from rainfall lasting for hours, sometimes days, and covering a wide area of the watershed.

Single event floods

This is the most common type of flooding in which widespread heavy rains of 2 to 3 days’ duration over a drainage basin results in severe floods. Such heavy rains are associated with cyclonic disturbances, such as storms, slow moving depressions etc., during the summer monsoon season when air moisture content is very high. In India most floods belong to this category.

Multiple event floods

Sometimes heavy rainfall occurs when successive weather disturbances follow each other closely. Floods in the Indo-Gangetic plains and central Indian regions often are caused by the passage of a series of upper air cyclonic circulations, low-pressure areas or depressions from the Bay of Bengal, more or less along the same track.

Seasonal floods

These are floods that occur during different seasons. The summer monsoon season experiences a large number of floods, since major storm activity occurs during this season. The southern half of the Indian peninsula experiences floods mostly during the winter monsoon season. These floods are caused by heavy rainfall over a drainage basin. However, floods can also occur due to unusually high water levels of lakes fed by a river. Sometimes flood events are caused by events other than rainfall e.g. coastal floods, floods caused by dam failures and estuarine floods.

Coastal floods (or tidal flooding)

Storm surges, tidal waves or earthquakes occurring in the ocean generally cause these floods. The surge is the outcome of piling of seawater against the coast due to strong winds generated by a cyclonic storm. The surface waters are driven towards the coast, where due to shallow water the return flow is retarded by the frictional force of the seabed. If the surge takes place near the mouth of a river falling into the sea, the river flow is held up due to the surge that results in severe flooding over and near the coastal areas. Such coastal floods often occur along the east coast of India during summer and winter monsoon months due to the activity of tropical cyclones/depressions in the Bay of Bengal.

Estuarine flood

Estuaries are the only portions of the coastline where the normal tide meets a concentrated seaward flow of fresh water in a river. The interaction between the seaward flow of fresh water in the river and landward flow of saline water from the sea during high tides may result in opposing land water flows, causing a wall of water. Sometimes the funnel shape characteristic of many estuaries causes an increase in high water levels in the upper narrow reaches of the river. These types of floods are mostly experienced in deltaic areas of rivers along the coasts and are not considered serious floods.

Apart from the above factors, occasionally Himalayan rivers experience minor to medium floods due to a sudden rise in temperature which causes quick melting of snow and glacier ice in the upper reaches of rivers. Floods also occur due to heavy rains over snowfields having thick snow cover. Such floods occur during the summer months in the plains area adjoining the Himalayas. Floods of this type are rather uncommon and occur mostly in the Himalayan valleys and do not cause large-scale destruction or damage on the plain.

Floods caused by dam failure

A dam failure or collapse obstructs the flow of water in a river by glacial tongues moving down the mountain slopes. Landslides across rivers flowing through hills cause serious floods in the downstream areas due to pressure of accumulated water upstream of the failure. In 1979, the collapse of the Machhu Dam in Gujarat State of India caused the loss of about 10,000 human lives.

2.4 Causes of floods

2.4.1 General causes of floods

The causes of flooding, which are discussed in more detail in later chapters, are summarized in the upper part of Fig. 2.4-1. Most river floods result directly or indirectly from climatological events such as excessively heavy and/or excessively prolonged rainfall. In cold winter areas, where snowfall accumulates, substantial flooding usually occurs during the period of snowmelt and ice melt in spring and early summer, particularly when melt rates are high. Flooding may also result from the effects of rain falling on an already decaying and melting snow pack. An additional cause of flooding in cold winter areas is the sudden collapse of ice jams, formed during the break-up of river ice.

Major landslides may cause flooding in two ways. First, pounding occurs behind the debris dam across the valley causing upstream flooding; then, as the debris dam is overtopped, its erosion or collapse delivers massive flows downstream.

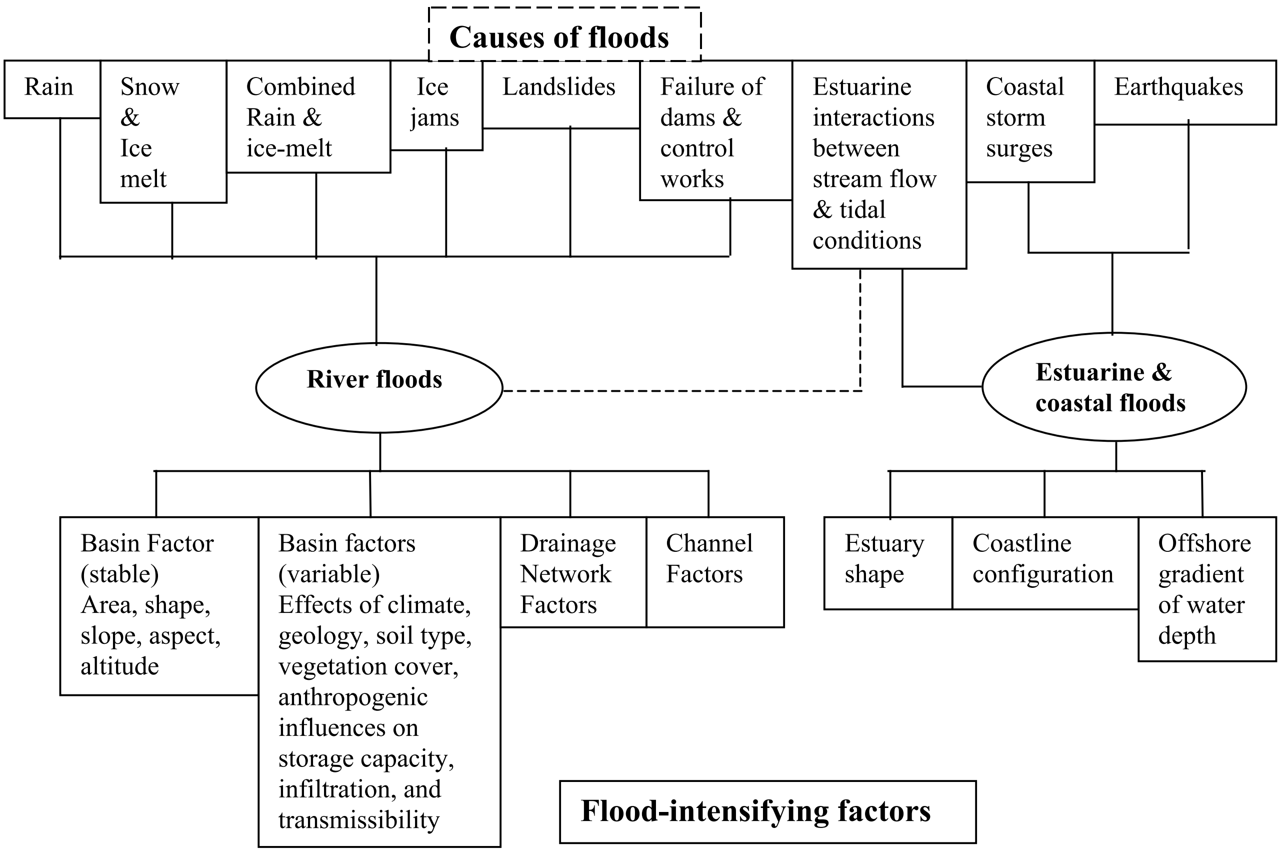


Fig. 2.4-1 Causes of floods and flood-intensifying factors (Source: Smith and Ward, 1999)

Estuarine and coastal floods are usually caused by a combination of high tides and elevated sea levels, plus large waves associated with storm surges that result from severe cyclonic weather systems. In estuarine and coastal areas protected by walls or embankments, inundation may result from either overflow, when the water level exceeds the level of the crest of the defense, or from overtopping, when the combined effect from waves and water level results in waves running up and breaking over the defense, or from structural failure of the defense (Burgess and Reeve, 1994). When a storm surge coincides in an estuary with large inflows of river water, flood conditions in the estuary result (as shown by the broken line in fig. 2.4-1). Estuary and coastal flooding may also be caused by tsunamis which result from the increase in amplitude of seismically generated long ocean waves when these enter shallow coastal waters.

2.4.2 Short-term causes

Monsoon downpour

An increased amount of precipitation can cause flooding. For example, an above-normal monsoon downpour in the Ganges-Brahmaputra-Meghna drainage system is thought to be the primary cause of the 1988 flood in Bangladesh (Government of Bangladesh (GOB) and UNDP, 1989; Brammer, 1990). It is not known, however, if the heavy precipitation is actually an effect of other processes such as the greenhouse effect or destruction of forests in the upstream region.

Synchronization of flood peaks

The synchronization of flood peaks for major rivers may take place within the same period, which may cause a sudden increase in the water level in virtually all areas of the Bangladesh (GOB and UNDP, 1989; Brammer, 1990). While the synchronization of flood peaks can explain the cause of the 1988 flood, it fails to explain the reason for an overall increased propensity for low frequency floods in recent years (such as those which occurred in 1974, 1984, 1987, and 1991). The answer might lie in other long-term processes that reduce the water-carrying capacity of the drainage system and decrease land elevation with respect to the base level of the rivers in Bangladesh.

2.4.3 Long-term causes

Local relative sea level rise

The ultimate destination of most rivers is the ocean. Land elevation is measured with respect to sea level in an area. Therefore, any change in sea level causes land elevation to change. At the present time, sea level is rising globally (Pilkey et al., 1989). If sea level rises in an area at a rate faster than the rate of land aggradations due to sedimentation, then land elevation decreases. Any decrease in land elevation can cause increased inundation by rivers overflowing at bankfull stage. The rate of local relative sea level rise is 7 mm/year around the coastal areas of Bangladesh (Emery and Aubrey, 1990). An increase in sea level raises the base level of rivers, which in turn reduces the gradient of river flow. As a result, the discharge of rivers decreases as the water flow becomes sluggish, creating a backwater effect further inland. The backwater effect caused by sea level rise can result in more flooding of land from "piled up" river water inland (Warner, 1987). This certainly seems to be one of the reasons for the increase in flood intensity in recent years in Bangladesh.

Inadequate sediment accumulation

The only way for land to counter the effects of a rising sea is for sediment to accumulate at a rate that is sufficient to keep pace with the rate of sea level rise. Limited data show that the average sediment accumulation rate for the last few hundred years in the coastal areas of Bangladesh is 5-6 mm/year, not enough to keep pace with the rising sea level (Khalequzzaman, 1989). As a result, net land elevations must have decreased over time, resulting in more flood inundations.

Subsidence and compaction of sediments

Sediments on a delta plain are rich in decomposed organic matter, and are subject to compaction due to dewatering and the weight of the overburden. Most deltas subside due to the weight of the thick sediment layer. Subsidence along with compaction reduces land elevation with respect to the rising sea level (Pilkey et al., 1989). Even though the rate of subsidence and compaction are not yet well documented, based upon knowledge about processes active in other deltas, it can be assumed that Bangladesh's delta is also undergoing subsidence and compaction.

Riverbed aggradations

Due to relatively higher settling velocity, large-grained sediments are deposited near the source area on the riverbeds, forming sand bars. The river gradient decreases rapidly if sedimentation continues on riverbeds. Because of low gradients and high sediment loads, riverbeds of most rivers in Bangladesh aggraded very quickly. Riverbed aggradations are most pronounced for the Ganges and its tributaries. From the border with India to the point where the Ganges meets the Brahmaputra, the riverbed has aggraded as much as 5-7 meters in recent years (Alexander, 1989b). Riverbed aggradation is so pronounced in Bangladesh that changes in riverbed level can be observed during one's lifetime. For example, the Old Brahmaputra was navigable for steamers until 30 years ago, but is presently an abandoned channel. This situation is true for many other distributaries of the Ganges and Meghna such as the Madhumati, the Bhairab, the Chitra, the Ghorautra, etc. Riverbed aggradations reduce the water carrying capacity of rivers, causing them to overflow their banks. This recent increase in riverbed levels has contributed to the increased flooding propensity in Bangladesh.

Deforestation in the upstream region

A rapid increase in population on the Indian sub-continent this century has resulted in an acceleration of deforestation in the hills of Nepal to meet the increasing demand for food and fuel wood (Ives, 1989; Sharma, 1991). Deforestation of steep slopes is assumed to lead to accelerated soil erosion and landslides during monsoon precipitations. This in turn is believed to contribute to devastating floods in the downstream regions such as in Bangladesh (Hamilton, 1987; The New York Times, 1988; Alexander, 1989a). However, Hofer 1998, after 12 years of research in Himalayas, concluded that it has not been possible to find significant correlation between human activities in the mountains (e.g. forest removals) and catastrophes in the plains (e.g. floods).

Damming of rivers

Damming a river reduces the velocity of water flow downstream from the dam. As a result of reduced velocity, the sediments carried by the river start to settle down faster on the riverbed, causing riverbed aggradations and in turn reducing the water carrying capacity of the river (Shalash, 1982). The Farakka Barrage on the Ganges has already caused tremendous damage to the agriculture, navigation, environment, and hydrodynamic equilibrium in Bangladesh (Shahjahan, 1983; Siddiqui, 1983; Broadus et al., 1986; Khalequzzaman, 1989).

Soil Erosion due to tilling

Plowing makes the land surface more susceptible to soil erosion. Surface run-off can easily wash away the topsoil from cultivated land. This surface erosion reduces land elevation, which in turn increases flood intensity in an area. The land elevations in Bangladesh must have been reduced over time due to cultivation. Aside from this, the tilling on the mountain slopes of the Himalayas is thought to be responsible for massive soil erosion in Nepal (Dregne, 1987; Thapa and Weber, 1991; Sharma, 1991) that eventually caused rapid riverbed aggradations in Bangladesh (Alexander, 1989a).

Excessive development

Rapid population growth creates extra pressure on the land in already overcrowded areas. Agricultural lands give way to housing developments and roads. This rapid development and urbanization has aggravated the flooding problem in many countries.

Prior to urbanization there is a greater lag time between intense rainfall and peak stream flow. After urbanization the lag time is shortened, peak flow is greatly increased, and total runoff is compressed into a shorter time interval – favorable conditions for intense flooding. For example, in a city that is totally served by storm drains and where 60% of the land surface is covered by roads and buildings, floods are almost six times as likely to occur than before urbanization (Pipkin and Cunnings, 1983).

Seismic (Earthquake) and neotectonic activities

Earthquakes cause movement of the land, and this can change the topography of the region and alter river courses. A sudden change in a river course can cause substantial flooding. For example, the Old Brahmaputra changed its course to its present location following an earthquake in the mid eighteenth century (Er-Rashid, 1978). The northern regions of Bangladesh are earthquake-prone (Morgan and McIntyre, 1958). Neotectonic activities (recent movements in the Earth's crust) are affecting river courses in the area. The Madhupur tract and the Barind tract are undergoing such neotectonic activities (Morgan and McIntyre, 1958). Most recent floods have occurred approximately simultaneously with earthquake activities. For example, the 1950 earthquake in Assam caused "swallowing" of the Brahmaputra, by causing it to breach its banks and flood the region (The Times of India, 1988). The floods of 1988 and 1991 coincide with earthquake activities in northern parts of Bangladesh (The Times of India, 1988; The New York Times, 1991). A powerful earthquake occurred on October 20, 1991 in northern India, which was preceded by a flood in Bangladesh and was followed by another flood in the Ganges valley in India (The Philadelphia Inquirer, 1991).

Floods can be both a cause and an effect of an earthquake. Floodwater places an extra hydrostatic pressure on unstable and mobile crustal blocks. If this extra pressure reaches the threshold strain limit along a fault zone or plate boundary within the Earth's crust, it can cause an earthquake to occur due to a sudden release of the strain energy accumulated over time. Similarly, an earthquake can change the surface drainage pattern and consequently the course of a river, causing sudden flooding in an area. Even though the cause and effect relationship between floods and earthquakes is not very clear, historic records suggest a relationship between these two phenomena. The recent earthquake of September 17, 2000 in Hyderabad, India is very likely due to the intense flooding in the region, although the Hyderabad is located in a very stable Indian shield (http://www.rediff.com/news/2000/sep/17quake.htm).

Greenhouse effect

The world is about to enter a period of rapid warming. Should the greenhouse effect become a reality, the low-lying coastal areas will be affected by a rising of sea level of even greater magnitude (Milliman et al. 1989; Gable and Aubery, 1990). Bangladesh will be severely impacted by such an increase in sea level (Broadus et al., 1986; Khalequzzaman, 1989; Ali and Huq, 1989; Brammer 1989; Hossain 1989). Besides many other adverse environmental, economic, and climatic consequences (Huq and Ali, in press), the base level of all rivers will change following any change in the sea level. The effect on flooding of a higher base level resulting from a rising sea level has already been discussed earlier in this section. The greenhouse effect will also increase the amount of rainfall and storminess, which will further aggravate the flood problem.

Fig. 2.4-2 The house is seen during the Bangladesh flood of 1988 (Source: FHI, 1998)

2.4.4 Meteorological Causes of Floods in Asian countries

Heavy rainfall is the main cause of floods in India for any river basin. In India, heavy rainfall is normally associated with the summer and winter monsoons. During these monsoon periods, certain meteorological systems interact with the monsoon circulations, causing heavy to very heavy rainfall. Meteorological situations responsible for causing floods in the Indian rivers have been studied by Parthasarthy (1955), Bose (1958), Dhar (1959), Dhar and Changrani (1966), Jegannathan (1970), Dhar et al. (1975, 1980, 1981, 1986, 1989, 1990, 1991, 1992, 1993, 1994). Ramaswamy (1987) pointed out following synoptic systems for the cause of severe floods:

- Tropical disturbances such as monsoon depressions and cyclonic storms moving through the country from the neighboring seas of the Bay of Bengal and the Arabian ocean.
- Passage of low-pressure system or monsoon lows.
- Break monsoon situations generally prevailing during July and August.
- Active monsoon conditions prevailing over a region for a number of days and offshore vortices along the west coast.
- Mid-latitude westerly systems moving from west to east.
- Mid-tropospheric cyclonic circulations over western region of the country.

Apart from the above meteorological situations there are man-made factors, which are responsible for causing serious floods in different parts of the country.

Monsoon depressions and cyclonic depressions

From June to September, river flooding is caused by the movement of monsoon depressions and cyclonic storms throughout India. These disturbances mostly originate from the Bay of Bengal and very rarely from the Arabian Ocean. As they move, these disturbances cause heavy to very heavy rainfalls along and near their tracks. Predicting the movement of these disturbances, therefore, is essential in the flood forecasting and warning system. These cyclonic disturbances during the monsoon months mostly form at the head of the Bay of Bengal and travel in a northwest to west direction through the Indo-Gangetic plains and its neighborhood after crossing the coast. Sometime after moving far into the interior of the country, these disturbances recurve and move towards the north or northeast and break over the foothills of the Himalayas under the influence of westerly troughs or western disturbances moving from west to east at higher latitudes. Associated with these disturbances, both the Arabian Ocean and the Bay of Bengal branches of the summer monsoon currents strengthen considerably and cause heavy to very heavy rainfall over the region. However, it has been observed that in the summer monsoon, heavy rainfall generally occurs in the southwestern sector of these disturbances. According to Rao (1976), heavy rainfall (7.5 cm and above) occurs over a belt of 400 km wide to the left of the track for a length of 500 km from the center of the disturbances. As a result of heavy rainfall, severe floods occur in the rivers of the region. These are generally known as single event floods. The floods on northern and central Indian rivers occur mostly due to heavy rainfall caused by the slow movement of these disturbances. The deltaic areas of Orrisa, Andhra Pradesh and also Tamilnadu (during winter monsoons) suffer frequently from the floods caused by these bay cyclonic disturbances at the time of their landfall.

Passage of low-pressure areas and upper air cyclonic circulations

Passage of low pressure areas both of ocean or land origin or movement of upper circulations during summer monsoon months often cause heavy rains and consequent floods. Low pressure areas are less intense than monsoon depressions but they form frequently during the monsoon months and their contribution to the rainfall in India is quite substantial. Unlike cyclonic storms/depressions, there is no regular account of the number of 'lows,' which occurred during summer monsoon months. However, Srnivasan et al. (1972) found that 87 lows, both of ocean and land origin, occurred during the 20-year period from 1950-1969. Recently, Nandargi (1995) found that 93 lows occurred over India during the summer monsoon period during the 10 years from 1984 to 1993, causing 557 low days. In general, lows have an average life span of about 4 to 6 days. In any certain year, the lows travel one after another in quick succession through north India, causing continuous heavy rainfall for a number of days. Such multiple events are responsible for causing serious floods in the rivers of north and central India such as the Narmada, the Tapati and the northern tributaries of the Godavari.

Fig. 2.4-3 A family tries to make its way to a safer place along a submerged express way in Kendrapara district. Makeshift 'boats' are used to ferry people and materials through the affected areas.

<u>Break situations during monsoon periods</u>

A 'break' monsoon situation occurs when the axis of the seasonal monsoon trough, which normally passes through Delhi, Kanpur, Patna and then to Kolkatta shifts northwards from its normal position and lies close to the foothills of the Himalayas both on surface and 850 mb synoptic weather charts. This particular situation results in heavy rainfall over the northeastern and central Himalayas and their adjoining plain areas (Dhar et al., 1984), while the rest of the country is under drought conditions with little rain. During break situations, due to heavy rainfall over Himalayan arid sub-Himalayan regions, floods occur in the rivers of northeast and central Himalayas i.e. Brahamaputra and its tributaries, Testa, Kosi, Gandak, Ghagra, Kamla Balan, Bagmati, and Rapti. During break monsoon days, areas under the Sikkim and eastern Nepal Himalayas and their neighborhood receive heavy rainfall, which is 50 to 300 percent or more of the daily rainfall over these areas, while the areas south as well as to the north receives less rainfall. A southward shift of the axis of the seasonal monsoon trough from its normal position results in a well-distributed rainfall over the central parts of the India and adjoining northern parts of the Indian peninsula. During a break situation, a paradox often arises in which flooded rivers from the Himalayas inundate areas in the Ganga plains, which are under drought conditions. Break situations very rarely last for more than a week at a time and generally occur in July and August of the summer monsoon season. During the break in July and August 1954, there were widespread floods in the Himalayan rivers from Gandak on the western side to the Brahamaputra on the eastern side. According to Partasarthy (1955), the plains of Bihar, Bengal, Orissa and southern districts of Uttar Pradesh suffered from partial droughts while north Bihar, Bengal and Assam experienced the fury of floods.

The floods and heat condition of underlying surface in the Tibetan Plateau

The East Asia monsoon is greatly affected by the Tibetan Plateau. In addition, snowmelt in the Plateau has a direct effect on Yangtze River floods. Heat conditions on the underlying surface on the Tibetan Plateau are one of the most important meteorological predictive factors. Mean temperatures of the Tibetan climate stations have been selected to represent the plateau's surface temperature. A correlation index between the mean monthly temperature in Tibet and the total amount of precipitation during flooding season in the Yangtze River basin was calculated. The temperature in March, August, and December in any given year has a significant correlation with the precipitation during the flooding season of the following year. The closest correlation is between August temperatures in the Tibetan Plateau with Yangtze River precipitation during the flood season the following year with the degrees confidence that reaches 0.99 (Lu and Ding, 1997).

Floods due to glacial lake outburst

Glaciers result from an accumulation of ice, air, water and rock debris or sediment. A glacier is a large enough quantity of ice to flow with gravity due to its own mass. Glaciers flow very slowly, from tens of meters to thousands of meters per year. The ice can be as large as a continent, such as the ice sheet covering Antarctica; or it can fill a small valley between two mountains. Accumulation of snowflakes stimulates glacier formation. Snowflakes fall to the ground and over time, lose their edges and slowly become tiny grains separated by air. Additional snowfall compresses underlying layers of snow grains that become loosely compacted with randomly oriented ice crystals and connected air spaces. Ice in this form that has survived a season is termed firn. Continuous compression removes air bubbles from firn and forms true glacial ice with a blue tone; it takes about 1,000 years for snow to form glacial ice.

Himalayan glaciers

River	**Major River System**	**Mountain Area (km^2)**	**Glacier Area (km^2)**	**% Glaciations**
Indus		268,842	7,890	3.3

Jhelum		33,670	170	5.0
Chenab	Indus system	27,195	2,944	10.0
Ravi		8,092	206	2.5
Sutlaj		47,915	1,295	2.7
Beas		12,504	638	4.4
Jamuna		11,655	125	1.1
Ganga		23,051	2,312	10.0
Ramganga	Ganga system	6,734	3	0.04
Kali		16,317	997	6.01
Karnali		53,354	1,543	2.9
Gandak		37,814	1,845	4.9
Kosi		61,901	1,281	2.1
Tista		12,432	495	4.0
Raikad		26,418	195	0.7
Manas		31,080	528	1.7
Subansiri	Brahamputra system	81,130	725	4.0
Brahamputra		256,928	108	0.4
Dibang		12,950	90	0.7
Luhit		20,720	425	2.0

Table 2.4-1 Principal Glacier-fed river systems of the Himalayas (after Hasnain, 1999)

The Himalayan glaciers receive annual accumulation mainly in the summer. The monsoon precipitation from June to September contributes about 80% of annual precipitation. Ageta and Higuchi (1984) called these glaciers summer accumulation types. These glaciers are different from the winter accumulation type, which are common in Europe and America. In summer accumulation type glaciers, which are common in Himalayan region, accumulation and ablation occur simultaneously. Under such conditions, summer snowfall sometimes changes to rain under warm air temperature conditions. New snow cover melts away quickly. Summer air temperature in the Himalayan region is an important factor, which controls ablation through albedo variation at the glacier surface. Ageta (1983) has estimated relations between summer mean air and accumulation, ablation and balancing during summer. Table 2.4-1 identifies some of the important glacier-fed river systems of the Himalayas.

Cloudburst floods

Cloudburst is very common in the Himalayan region. In 1963, a cloudburst struck the meadow of a tourist resort near Srinagar (J & K), which killed several people and caused a flash flood in the Lidar River. In September 1995, heavy incessant rain in the upper reaches of the Bias River and a cloudburst on the southern slope of Rohtang in the higher Himalayas formed a small dam debris flow north of Manali. The bursting of the dam generated a flash flood.

Fig. 2.4-4 Flood in India. Many neighborhoods in north and northeast India remain under water. -- Photos courtesy of the BBC **(Source: Disaters Relief, 2000)**

2.4.5 Flood with special events

Floods and sunspots

Recent research shows that solar activity has some effect on regional long-term global precipitation. (Wu and Gough, 2001). It is indicated that extreme flood years are usually when the 11-year periodical variation of sunspot relative number is either at its peak or its lowest values, especially at the lowest values.

Floods and El Niño

As the most remarkable connective signal between the global climate and sea, El Niño profoundly affects the world climate. There have been many studies on El Niño and its relationship to regional climates. Statistical analysis proves that most of Yangtze River floods occur in the years following El Niño. Taking the 1998 flood as an example, the 1997 El Niño was the most active in the last 100 years, which greatly affected the precipitation in the basins of Yangtze River. The precipitation during the winter of 1997 and spring of 1998 was 2 to 5 times greater than that during the same period in the past, with the main rain belt in the southern areas of Yangtze River. The rain belt then began to move to the upper and middle reaches with the central rain belt located at the middle reaches in June. The precipitation in this month reached 800 mm, twice the historical norm. In July, the central rain belt was in the Wuhan region where the mean monthly precipitation was 4 times normal. The precipitation on July 21-22, 1997 in Wuhan reached 221.5 mm and 175.2 mm respectively, both of which broke the historical record. In August, the rain belt arrived in the upper basins. Daily rainfalls of over 100 mm occurred in Three Gorges Reservoir, which caused several flooding peaks in the upper reaches. The above time and space distribution of precipitation raised the flood's level in the middle and lower reaches at the beginning, which when combined with the following heavy rains in the middle and upper reaches, resulted in extreme floods in entire reaches of the Yangtze River (Wu and Gough, 2001).

2.5 Flood-intensifying factors and conditions

As the lower part of Fig 2.2-1 shows, floods may be intensified by a number of factors. In the case of estuarine and coastal floods, intensification results largely from the funneling effects of estuary shape and coastline configuration, e.g. the Bengal, which causes an overall increase in sea level as water is driven into the narrower section. The overflow of sea defenses is less common than overtopping on the open coast, but is an important aspect of flooding in estuarine areas. The height of tsunami waves at their point of impact upon the coastline is dependent upon the offshore slope of the seabed, or upon the rate of decrease in water depth encountered as the tsunami moves towards the shore.

River floods may be intensified by factors associated either with catchments themselves or with the drainage network and stream channels. Few of these factors, however, operate either unidirectionally or independently. For example, area is clearly important in the sense that the larger the catchments, the larger the flood produced from a wide rainfall event. However, when the rainfall event covers only parts of catchments, the attenuation of the resulting flood hydrograph, as it moves through the channel network to the outlet, is likely to be greater in large catchments than in small ones. Some of the most complex relationships, those between the variable basin factors, have a significant influence on three important hydrological variables: water shortage, infiltration and transmissibility.

Water storage in the soil and deeper subsurface layers may affect both the timing and magnitude of flood response to precipitation, with low storage often resulting in rapid and intensified flooding. High infiltration values allow much of the precipitation to be absorbed by the soil surface, thereby reducing catchments flood response, and low infiltration values encourage the normally swifter over-the-surface movement of water leading to rapid increases in channel flow. In basins where most precipitation infiltrates the soil surface, flood response may be greatly modified by subsurface transmissibility, i.e. the ease with which water flows through the subsurface materials.

Apart from drainage patterns, channel and network factors within a drainage basin are essentially dynamic and their effects on flooding may change noticeably within a few hours. Of major importance is the proportion of the catchments area having interconnected water and waterlogged surfaces where the effective infiltration capacity is zero, so that all rain falling on such surfaces contributes directly and rapidly to stream flow. At the onset of rainfall, these source areas for quick flow may be restricted to the water surfaces in the channel network; but as rainfall continues, the source areas expand, causing a major increase in the volume of rapid runoff reaching stream channels.

Human activities frequently act as flood-intensifying factor by modifying key hydrological variables such as water storage, infiltration and transmissibility. The effects on flooding of anthropogenic influences associated with urbanization, agriculture, forestry and dam construction are obvious.

In summary, flood intensification depends on the following characteristics:

1) Basin characteristics
- Stable - area, shape, slope, aspect and altitude
- Variable - interactions between climate, geology, soil type, vegetation cover, wild life, human activities causing important differences in storage capacity of soil and bedrock, infiltration and transmissibility of soil and bedrock

2) Network characteristics
- Stable - pattern of network
- Variable - surface storage, channel length

3) Channel characteristics
- Stable - slope, flood control and river regulation works
- Variable - roughness, load, shape and storage

One of the most important of all flood-producing conditions is the total area of interconnected water and water-logged surfaces within the catchments where the effective infiltration capacity is zero and on which all falling precipitation contributes directly to stream flow.

2.6 Flood alleviation

Efforts have been made to control rivers over hundreds of years. Water management measures were undertaken for Ganges waters in India as early as the thirteenth century, although these were modest in the delta region. Very little was done to control Ganges River flows during the British period in India, probably because of the particular severity of flood flows compared with those which were successfully harnessed on the Punjab rivers.

Following several disastrous floods in Bangladesh, numerous international agencies were involved in developing many bilateral aid agencies to control floods (World Bank, 1990; UNDP, 1989; Hunting Technical Services, 1992). In 1995, water and flood management strategies were developed, taking into greater account multisectoral issues (BWDB, 1995). After 1998's disastrous flood, efforts were made to focus flood alleviation strategies, e.g. integrated water management, floodplain morphology and flood forecasting and warning. With the help of international agencies, efforts have been made to carry out physical civil engineering works such as upstream storage in dams, channel improvements, underground storage, shallow storage reservoirs and construction of embankments. Of these, only embankment construction was considered as a possible permanent solution to the problem of flooding. Non-structural activities could assist in protection of the population, particularly flood forecasting and warning and community based flood preparedness.

China has a long history of river and flood control on the Yangtze River, including building embankments downstream, constructing dams and reservoirs upstream, and returning cultivated land back to lakes.

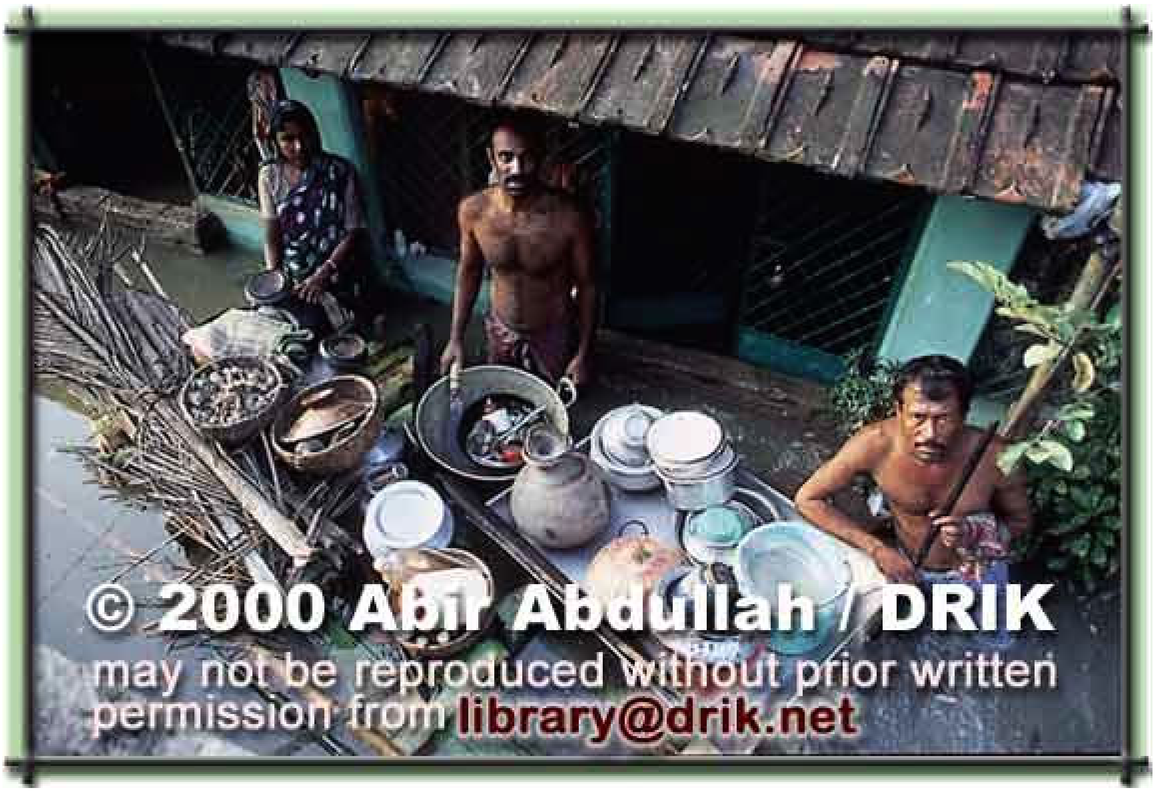


Fig. 2.7-1 Flood in Bangladesh. A family carrying all of their belongings and looking for a dry place as their house has gone under water. Satkhira, Bangladesh. October 6, 2000 (Source: ' 2000 Abir Abdullah / DRIK)

2.7 Human causes of flood hazard

As discussed in section 2.4, many causes of floods are attributed to human activities, such as deforestation in the upstream region, damming of rivers, and soil erosion due to tilling. Flood hazards are created by countless individual decisions that encourage the settlement and economic development of floodplains and flood-prone coastal areas. Historically, the process is well established. For example, in India floods are the most common feature since the dawn of civilization. At Mohen jo Daro, flood control structures existed as early as 2700 to 300 BC (Mackey, 1934). These structures, as well as storm water drainage works, show that heavy rains and consequent floods have been occurring regularly each and every year in different parts of India, even in those prehistoric times. The intrinsic land-use attractions of major floodplains and coasts have made these zones some of the most densely populated and hazardous settings in the world. Because flood hazards are essentially created by human decisions and actions, it follows that the social and political context for such actions is an important element in the selection of any subsequent flood mitigation schemes (Smith and Ward, 1999).

3 Damage due to floods in Bangladesh, China and India

3.1 Damage due to floods

In many countries of the world, floods are the most costly hazards in terms of both loss of human lives and material damage. The spatial scale at which this kind of phenomenon arises can be highly variable. Flooding can affect large continental area, but it can also occur as a very localized event. On the global scale, storms and floods are most destructive of natural disasters and cause the greatest number of deaths (Casale and Margottini, 1999).

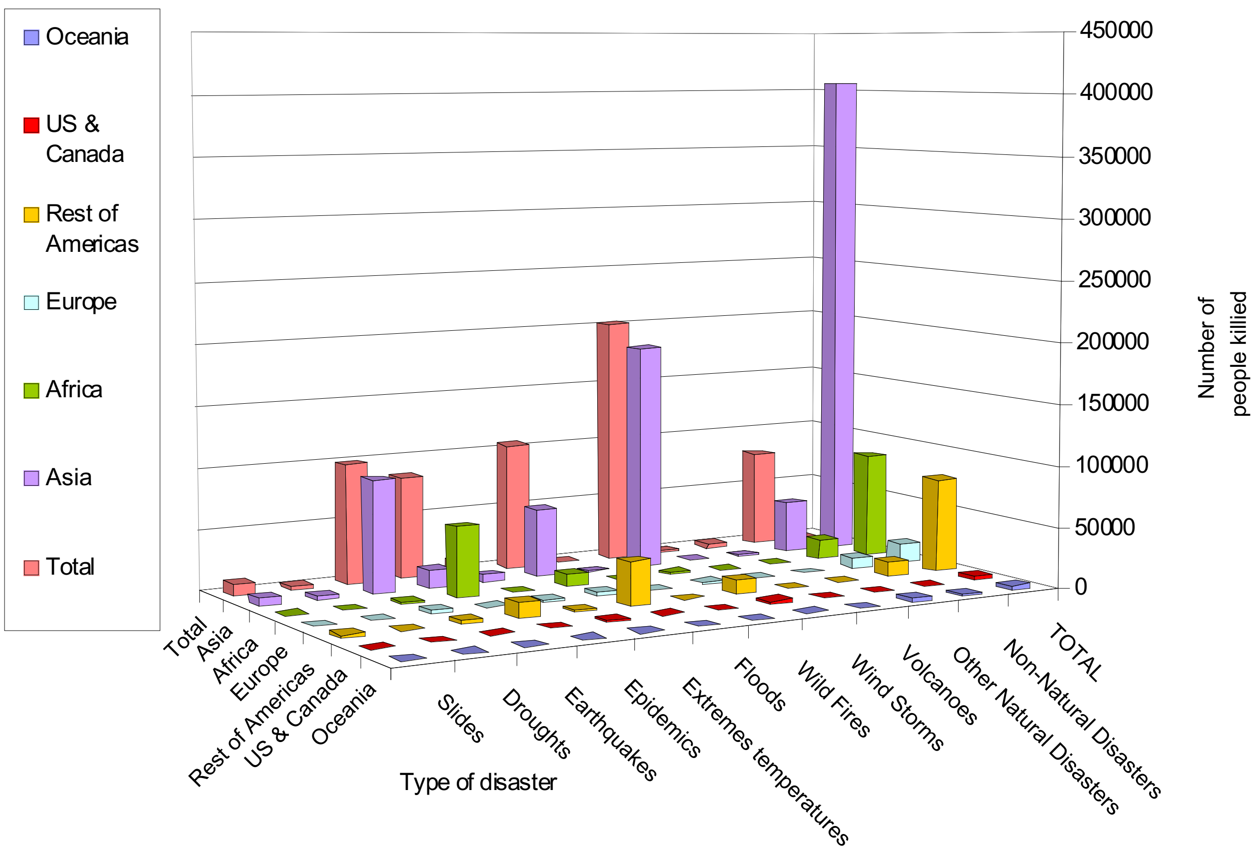


Fig. 3.1-1 Total number of people reported killed, by continent and by type of phenomenon (1990 to 1999, source: IFRC World Disaster Report 2000)

Every year thousands of people die by different disasters but the fate of many of them is never reported. Fig.3.1-1 shows the comparison of fatalities between the different continents. The United States and Canada are shown here as one continent as they are the two richest countries in the world in terms of land and resources. The graph shows that Asia and Africa are the most vulnerable continents where fatalities are much bigger than on other continents. In last 10 years, windstorms and floods killed thousands of people in Asia, which is more than 10 times higher than rest of the world.

The WWW system of WMO addresses the need for special severe weather warnings and meteorological advisories that are crucial for minimizing the losses from natural disasters. It is estimated that natural disasters annually claim nearly 250,000 lives and cost US $ 50 billion to 100 billion in property damage. Fig. 3.1-2 shows that over 84 percent of all significant damage in property is caused by disasters which are meteorological and hydrological in origin. For the forecasts or early warning of various types of natural hazards, reliable and accurate forecasts of meteorological and hydrological parameters are crucial.

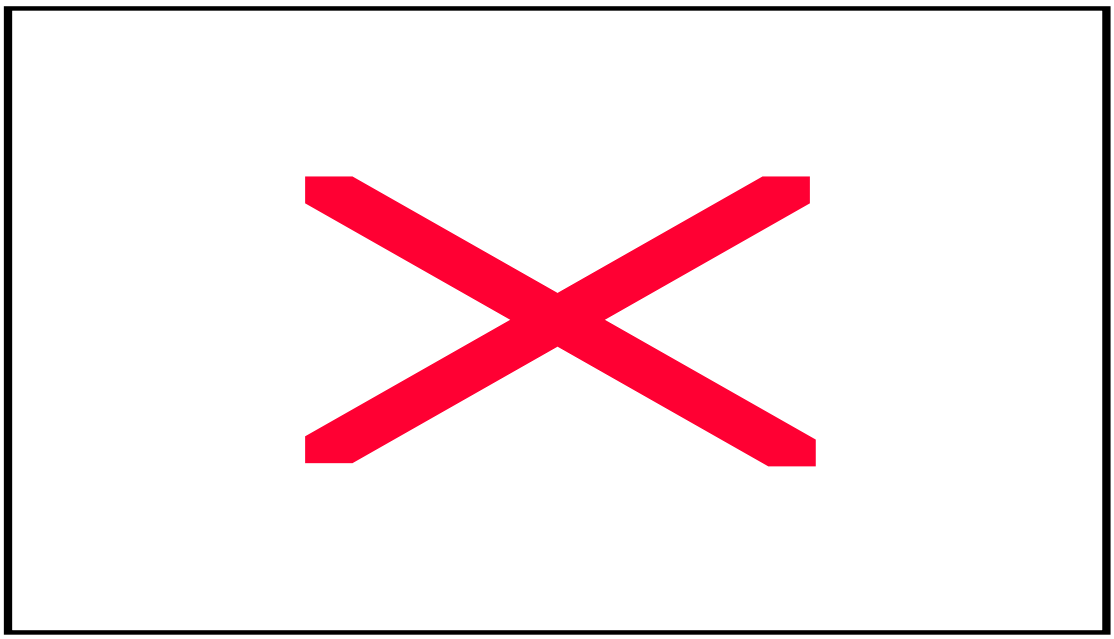


Fig. 3.1-2 Major disasters of the world

3.1.1 Floods in Bangladesh

Bangladesh is one of the countries with the highest frequency and most loss of life from floods hazards in the world. The problems stem from high population density and poor economic situations. The following table shows the relationship between the number of natural disaster events (floods, cyclones, landslides etc.) and the comparison in Bangladesh and United States. These numbers show that reported natural disaster events in the United States were over 3 times higher than in Bangladesh. However, the number of deaths in Bangladesh was 34 times higher.

Bangladesh is geographically located in the deltaic region of three enormous rivers, only 8% of whose catchments areas lie within its political boundaries (Fig. 3.1-1). It has experienced several calamities of different proportions. In recent years, the climatic events are worsening in intensity, duration and frequency.

Roughly two-thirds of Bangladesh is fertile arable land and a little over 10% remains forested. The country is home to the Royal Bengal tiger, leopards, Asiatic elephants (mostly migratory herds from Bihar), and a few remaining black bears. There are also abundant monkeys, langurs, gibbons (the only ape on the subcontinent), otters and mongooses. Reptiles include the sea tortoise, mud turtle, river tortoise, pythons, crocodiles and a variety of poisonous snakes. There are more than 600 species of birds. The best known is the mynah, with the most spectacular being kingfishers and fishing eagles.

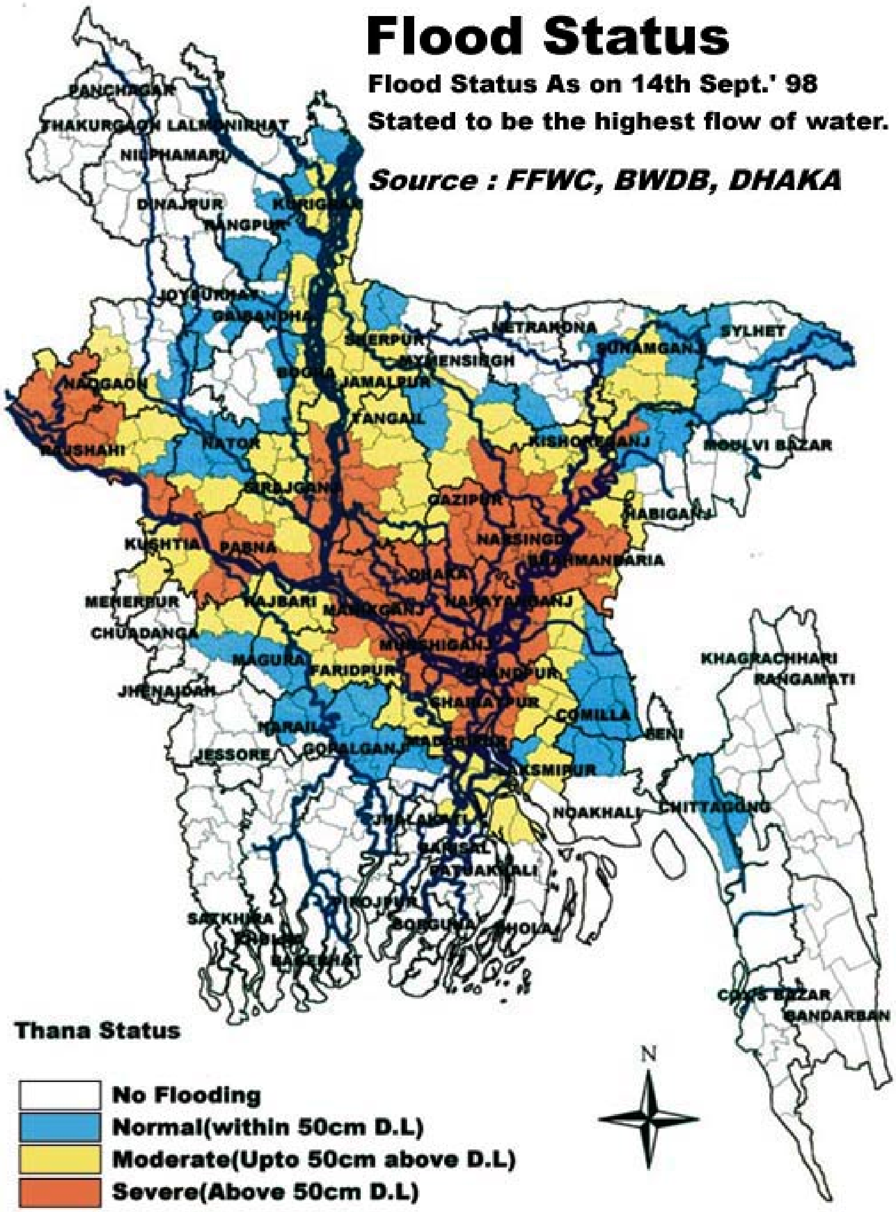


Fig. 3.1-3 Flood Status and river system of Bangladesh (Source: FFWC, BWDB, Dhaka, 1998)

The climate of Bangladesh is subtropical and tropical with temperatures ranging from an average daytime low of 21 degrees Celsius in the cold season to a high of 35 degrees in the hot season. Bangladesh has three main seasons: the monsoon or `wet' season from late May to early October; the `cold' season from mid-October to the end of

February; and the `hot' season (known in Bangladesh as the `little rainy season') from mid-March to mid-May. There is also a 'cyclone season' - May to June and October to November.

Fig 3.1-4 A son carries his mother on his back as he wades through flood waters to reach higher land in Satkhira on Sunday (Source: AP photo, 2000)

Bangladesh is nestled in the crook of the Bay of Bengal, surrounded by India (Fig. 3.1-3). It shares a border in the southeast with Myanmar and fronts onto the Bay of Bengal. The country is flat, and dominated by the braided strands of the Ganges-Brahmaputra-Jamuna delta, where Bangladesh ends and the sea begins is a murky zone of shifting sediments, watercourses, floodwaters and silt. Over 90% of the country is composed of alluvial plains less than 10 m above sea level, making it an inviting proposition to flood-prone rivers and tidal waves. The only relief from these low-lying plains occurs in the northeast and southeast corners where modest hills rise to an average height of around 240 m and 600 m, respectively.

Country	**Number of reported events**	**Number of deaths**
Bangladesh	86	150,242
USA	242	3,418

Table 3.1-1 A comparison of number of reported natural disaster events and fatalities in Bangladesh and USA (1990-1999, Source: CERD 2000)

In recent years the frequency of abnormal floods in Bangladesh has increased substantially, causing serious damage to lives and property. While the heavy monsoon downpour may be an apparent reason for the recent floods in Bangladesh, there are many underlying geologic causes that contribute to the flood problem over a long period of time. Fig.3.4 shows the number of people killed by floods in Bangladesh during 1900-1999.

Some statistics of damages caused by 1998 flood in Bangladesh:

1) LOSSES AND DAMAGES AS OF OCTOBER 4, 1998:
- Total area affected by flood – about 100,000 sq. km. (Area of Bangladesh is 148,393 sq. km.)
- Total shortfall of production: about 2.2 million MT
- Number of Districts – 52
- Number of Police Stations –366
- Number of Affected Union Parishad – 3, 323
- Number of Affected People – 309,160,351
- Affected Standing Crops in Acres – 1,423,320
- Number of Affected Homesteads – 980,571
- Number of Deaths – 918
- Cattle killed – 26,564
- Roads Damaged (km)– 15,927
- Embankments Damaged (km)– 4,528
- Number of Damaged Bridges / Culverts– 6,890
- Number of Educational Institutions damaged – 1,718
- Number of Flood Shelters – 2,716
- Number of people taking refuge – 1,049,525

2) NB: 52 Districts of the country affected more or less till today from October 4, 1998. The latest update of the flood-hit districts is as follows:
- The flood situation has turned normal in all affected 52 districts due to receding of water.
- Total death toll in flood affected districts: 918.
- The total sanction in flood affected areas since October 4, 1998 stands at 5 crore and 17 lakh 75 thousand taka and 91,062 MT of rice and 750 MT Wheat worth of taka 128 crore 53 lakh and 68 thousand. In addition to that 1 crore and 40 lakh taka in cash has been sanctioned from Prime Minister's Relief and Welfare Fund for the flood victims

3) Floods kill over 700, millions homeless in India, Bangladesh (CNN September 26, 2000)
- Rescue crews used boats and military helicopters to help some of the millions of people washed out of their homes by floods believed to have killed more than 700 in India and Bangladesh.
- Authorities tried to ferry victims to higher ground, but most remained marooned atop buildings. Air force helicopters dropped food and water purification packets.
- The vast majority of the deaths were in India, but the toll in both countries was expected to rise, and waterborne diseases were expected. Many villages were cut off as floods inundated roads.
- Almost all districts on either side of the southern India-Bangladesh border were affected since September 18, 2002 when late monsoon rains sent sudden water over riverbanks and dams. The floods submerged highways, villages and the

homes of more than 10 million people in eastern India and 200,000 in Bangladesh.

- In the Indian state of West Bengal, reports indicated “652 people were feared dead, more than half of them in Murshidabad district.”

3.1.2 Floods in China

The Yangtze River in China is the third largest river in the world, and is important to human society in China. Since ancient times, people have suffered from floods and flood disasters. Floods are related to the rising mechanisms at the level of the river and also broader ecological characteristics of drainage basins. Causative factors of Yangtze River floods are related to physical geography and related to human activities. The physical geographical factors relating to Yangtze River floods are varied.

Fig. 3.1-5 A Chinese man struggles to carry his bicycle through fast-flowing waters in a flooded stret in the Daijiashan district of Wuhan, near the Yangtze River yesterday. (Photo by The Associated Press, 1998)

Precipitation anomalies are key flooding mechanisms. It is commonly known that the East Asia Monsoon generally controls China’s climate, which means that most of China’s annual total rainfall occurs during the summer season. Because of the variations in monsoons, yearly rainfall totals fluctuate greatly, especially during the flooding season. The duration and intensity of rainfall during the flooding season is affected mainly by West Pacific Subtropical High Pressure (WPSHP) systems. The WPSHP lingers over this area for a long time, causing excessive rainfall in Yangtze River basins. Apart from WPSHP, some other important meteorological factors include westerly belts, low-level jets, and short waves. These meteorological factors act to bring southern moisture to Yangtze River drainage basins, forcing northern cool air masses to clash with southern warm air masses, thereby producing rain in this area. Nearly all past floods have resulted from this type of weather system.

The main problem in the hydrograph is the limited capacity of flood discharge in the middle reaches of the Yangtze River, especially in the reach of Jing-Jiang. Since most runoff in Yangtze River floods are generated in the upper basins, this limitation has a bottleneck effect on floods in the middle reaches. According to the observed data, the capacity of flood discharge in Jing-Jiang is about 60,000 M^3/s. Since 1892, there have been more than 24 years in which flood discharges have exceeded this capacity, each time causing great damage.

The impacts of human activities on the Yangtze River's ecological environment have been discussed in detail (Yijin et al., 1996). Human activities in Yangtze River drainage basins can be traced back to ancient times. However, only in modern times have these activities caused much disturbance and damage to the ecological environment. Over the last 530 years, flooding frequency has increased obviously in the last 200 years. There is a tight connection between such change and a degraded ecological environment. The main effects of human activities on the basins are:

- Deforestation along the upper basins has resulted in much soil loss. Mud and sand carried with the floods has been deposited on the riverbed, especially in the middle reaches of the river. The riverbed in Jing-Jiang now is 8-15m higher than the flood plain.
- With increasing population, many lakes have been enclosed for cultivation. For example, the number of lakes is down from 856 (1930s) to 577 (1990s) in the Jiang-Han plain. The diminishing number and size of lakes along the river weakens the attenuation of flood peaks. Further, many lakes are separated from the river, causing a rapid decrease in the Yangtze River flood storage capacity. The Yangtze River is historically a flooding river. There were 214 floods from the Han Dynasty (185 B.C.) to the Qing Dynasty (1911A.C). There were 14 big floods from 1921-2000. Fig. 3.1-5 shows the number of people killed by floods in China from 1900 to 1999 and Table 3.1-2 shows mainly floods from 1931-1954.

Major flood year	**1931**	**1935**	**1949**	**1954**
Number of people affected (thousands)	2,900	2,264	2,721	1,888
Number of people killed (thousands)	145.4	142	5.7	30

Table 3.1-2 Number of people killed by major floods in Yangtze River from 1931-1954 (Source: Tang, Q. "Chinese river and hydrology")

3.1.3 Floods in India

In India, floods have occurred since the dawn of civilization. At Mohen jo Daro flood control structures existed as early as 2700 to 300 BC (Mackey, 1934). These structures as well as storm water drainage works there show that heavy rains and consequent floods have occurred regularly each year in different parts of in India even in prehistoric times. On an average, until about the mid seventies, about 78 lakh hectares of land was affected by floods and the average flood damage per flood season was estimated to be 240 crores of rupees (Verma, 1978). It is estimated the average annual damage due to floods is 7,681 million rupees. On an annual average, as many as 1,495 human lives are lost; in the year 1977 alone 11,316 lives were lost. Flood losses are increasing yearly due to increasing population and consequent encroachment of low lying flood prone areas of the country (INAE, 1990). In India, floods over most parts of the country generally occur during the southwest monsoon season from June to September. In the southern half of the Indian peninsula, floods also occur during the northeast monsoon season from October to December. During the four monsoon months from June to September, the country receives about 76% of its annual rainfall, about 117 cm on an average (Dhar et al., 1981).

The major river basins in India can be classified into two groups:

- Rivers of the Himalayan region
- Rivers of Peninsular India

The melting of snows and glaciers from the great Himalayan range during spring and summer, and rain during the monsoon season, feed the Himalayan River. The behavior of the Himalayan region is very uncertain and depends on rainfall and snowmelt. These rivers carry significant flows during dry weather due to snowmelt, and minimum flows during winter. The peninsular rivers originate at much lower altitudes, flow into more stable areas and are more predictable in their behavior. The flow of these rivers is only controlled by the heavy discharges during the monsoon season.

From the standpoint of flood problems, the rivers have been grouped into following four regions (NIH, 1993):

- Brahmaputra region
- Ganga region
- Northwest region
- Central Indian and Deccan trap region

The problem of floods varies from basin to basin. The magnitude and intensity of floods also varies and is dependent upon streams and drainage networks in the region. The maximum streams originating from the Himalayan region meet in the Ganges and Brahmaputra Rivers, creating great risk of flood occurrence. The most flood-prone areas lie in the Brahmaputra basin and the northern sub-basins in the Ganga basin. Annual flood damages in the Ganga basin are about 60% of the country's total. The total area liable to floods is about 40 million ha. The Rashtriya Barh Ayog (RBA), a national agency which is responsible for flood-related problems in India, estimates during the period 1953-1978, about 8.2 million hectares of area was affected by floods every year. Approximately 3.5 million hectares, or 42.7%, was cropped area. Annual average flood-affected area for the period 1970-1978 is about 11.9 million hectares, of which 5.4 million hectares were cropped area, showing an increasing trend in the flood-affected area (NIH, 1993). In India, the need for flood control and management is increasingly important, and the following measures have been implemented:

- Sound watershed management through extensive soil conservation
- Catchments area treatment
- Preservation of forests and increasing forest area
- Construction of check dams

- Adequate flood cushion for water storage
- Establishment of forecasting networks along with regulation of settlements and economic activity in flood plain zones
- Use of structural measures (embankments and dykes) as well as non-structural measures like flood forecasting and warning
- Flood plain zoning

Items	
Land area affected	7.56 million hectares
Population affected	32.03 million
Human lives lost	1,504
Livestock lost	96,713
Houses damaged	11,683
Houses damaged (cost)	Rs. 136.615 crore
Crop damaged	Rs. 460.07 crore
Public utilities damaged	Rs. 377.248 crore
Total losses	Rs. 982.126 crore

Table 3.1-3 The average loss over the past four decades

The hydrologic regime of the Brahmaputra responds to the seasonal rhythm of the monsoon and freeze-thaw cycle of Himalayan snow in the backdrop of a unique geo-environmental framework. The river carries a mean annual flood discharge of 48,160 m^3/sec at Pandu (India) where the highest recorded flood was 72,748 m^3/sec (1963) with a recurrence interval of 100 years. The flow hydrograph of the river is marked by exceedingly high variability of discharge during the monsoon high flow season – June through September. The average annual rainfall in the basin is 230 cm, with a marked variability in distribution over the catchments. Rainfall in the lower Himalayan region amounts to more than 500 cm per year, with higher elevations getting progressively lesser amounts. Occasionally, the rainfall intensity is exceedingly high, causing flash floods, landslides, debris flow and erosion. Few extreme climatic events recorded so far in the Eastern Himalaya have been analyzed. Their hydrological consequences are discussed mainly in regard to water-induced mountain disasters such as floods and landslides. The changing land use (mainly deforestation) and development, as well as population pressures in the region and their hydrological implications, are also highlighted with the help of selected illustrations. The impact of Himalayan neotectonics on the hydrologic regime of the Brahmaputra especially in regard to the 1897 and 1950 earthquakes (both of Richter magnitude 8.7) is discussed based on the analysis of observed hydrological data. The pattern of accumulation and depletion of snow and glacial cover in the Tista and Kameng sub-basins of the Brahmaputra is delineated using satellite remote sensing technique and melt water runoff is estimated. Strengthening of the hydro-meteorological monitoring network in the Eastern Himalayas especially with respect to the upper catchments of the Brahmaputra River should be considered of primary importance for sustainable development of the immense water resources potential, preservation of its unique ecological wealth and for management of natural hazards.

The average loss due to floods over the past four decades is shown in Table3.1-3.

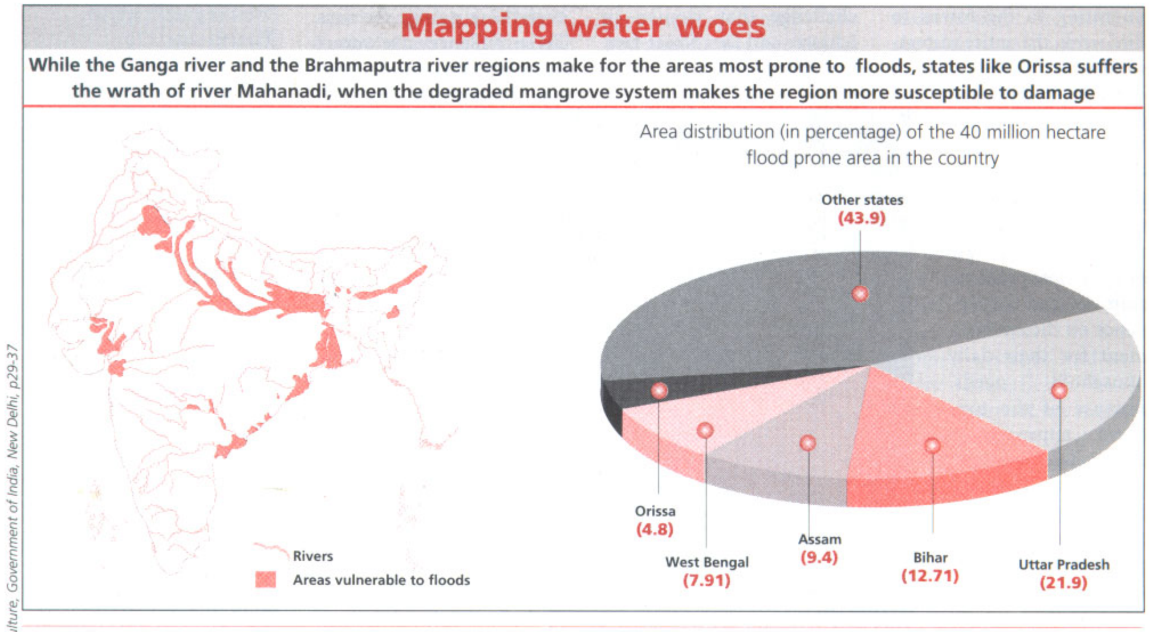


Fig. 3.1-6 Nearly 40 million hectares of land is vulnerable to floods, with about eight million hectares flooded annually

India receives an annual rainfall of 400 million-hectare meters, of which 75% is received in four months. Floods generally follow with devastation. In the last four decades, the country has lost about Rs. 9,720 million in damages to crops, public utilities and houses. Nearly 40 million hectares of land is vulnerable to floods, with about eight million hectares flooded annually (Fig. 3.1-6). Ecological degradation caused by humans adds to the problem resulting from erosion, poor natural drainage and related problems.

Although still a point of controversy, one of the causes of increased flooding in Bangladesh can be traced to Nepal and India (Assam), where the majority of the rivers originate. Massive deforestation of the mountainsides has significantly reduced the Himalaya's capacity to absorb the monsoon rains, and it has greatly increased the amount of eroded soil that is carried by the floodwaters.

Flooding is the main hazard in the Ganges River basin. Although occurrence of floods has been an age-old phenomenon in the basin areas of this region, the extent of damage caused by the hazards has increased significantly in recent years. The Ganges has experienced major floods in 1954, 1962, 1966, 1972, 1974, 1978, 1983, 1986, 1988, 1996, 1998, and 2000.

Fig. 3.1-7 An aerial view shows rising floodwaters at Karnool town in the Cuddapah district, some 420 km south of Hyderabad October 20, 2001. Andhra Pradesh on Saturday began counting losses and providing relief to victims of floods in which at least 73 people were killed earlier this week (Source: Reuters Limited, 2001)

3.2 Historic analysis of floods

3.2.1 Location of large flood events in Bangladesh, China and India

Many floods have now been imaged by satellite or airborne sensors and translated into maps of inundation extents by Dartmouth Flood Observatory staff. Dartmouth Flood Observatory has built an archive. The information presented in this archive is derived from a wide variety of news, governmental, instrumental, and remote sensing sources. It is presented in order to facilitate research into the causes of extreme flood events, provide international warning of such floods, and improve widespread access to satellite-based measurements and mapping. The archive is "active" because current year events are added immediately. Analysis using remote sensing data also continues on past events and such additional information is added to this archive as it becomes available (Dartmouth Flood Observatory, 2002). Fig. 3.2-1 shows the location of large flood events in Bangladesh, China and India from 1985 to 2001.

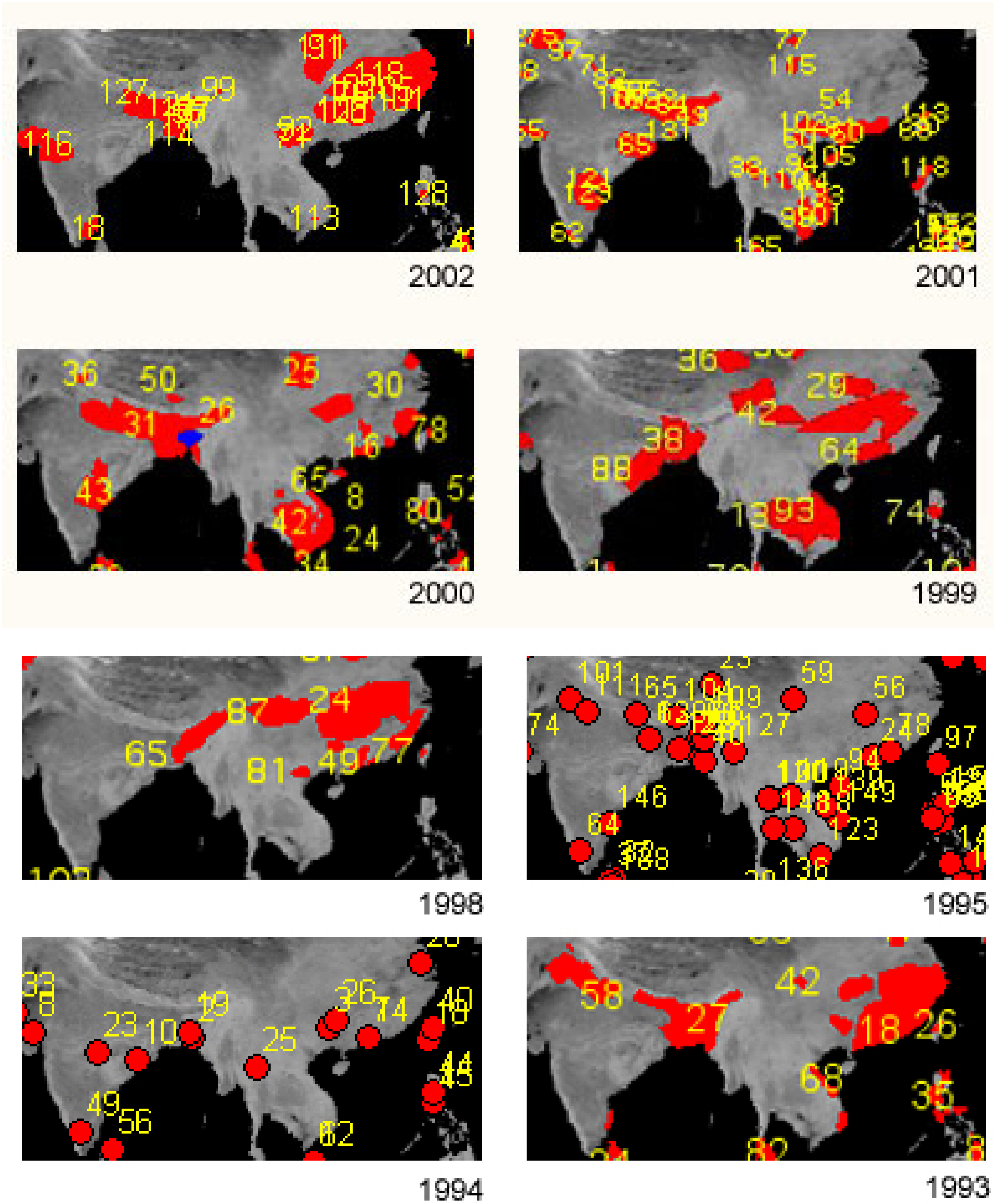


Fig. 3.2-1 The location map of large flood events in Bangladesh, China and India from 1985 to 2001 (Source: Dartmouth Flood Observatory, 2001, http://www.dartmouth.edu/artsci/geog/floods/), **to be continued on the next page**

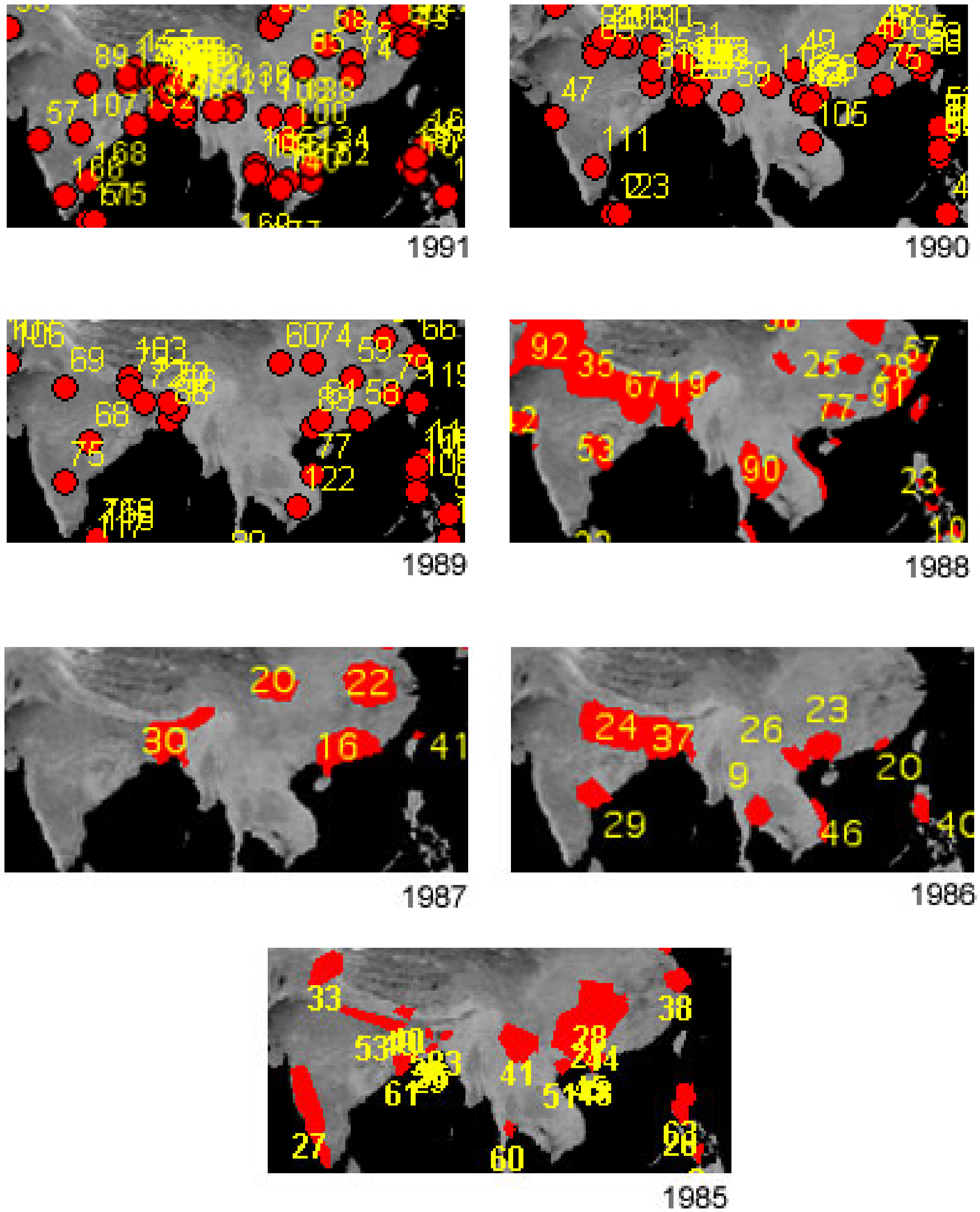


Fig. 3.2-1 The location map of large flood events in Bangladesh, China and India from 1985 to 2001 (Source: Dartmouth Flood Observatory, 2001, http://www.dartmouth.edu/artsci/geog/floods/)

3.2.2 Ganges/Brahmaputra and Yangtze River basins

Table 3.2-1 shows a history (1985-2001) of the register of large flood events in the Ganges/Brahmaputra and Yangtze River basins.

Table 3.2-1 A history (1985-2001) of Register of Large Flood Events in Ganges/Brahmaputra and Yangtze river basins of Bangladesh, China and India (Source: Dartmouth Flood Observatory, 2001)

Location	Began - end	Known dead	Number displaced	Damage estimate	Flood type	Hectares or Acres flooded	Geographic flood extents (km^2)	Notes and comments
1985								
N. India	08/01/ -10/31/	90			Monsoon rains			Three months of unusually intense Torrential monsoon rains
E. India	10/18/- 10/20/	38	30,000		Tropical storm			200 missing; 500 villages had access cut off; deaths occurred by house collapse, drowning; storm came from Bay of Bengal, storm surge also likely involved. Orissa was washed away.
1986								
India and Bang	09/22/ -10/10/	India: 19. Bang: 30	India: 500,000. Bang: 200,000		Monsoon	Bang: 2,890 sq miles; 1.3 million acres crops		"Meteorologists said more than 16 inches of rain fell on Calcutta and surrounding districts between Tuesday evening and Friday night, causing the Ganges River to breach its banks in many places."
1987								
Bang and NE. India	07/23/ - 09/24/	Bang: 200,000 -- India: 300,000	Bang: 1,000,000,000		Sustained heavy rains – Monsoon season	Bang: 9,000 square miles	240,100	Bangladesh "According to rough official estimates, crops on 2.5 million acres of land have been affected, most of them beyond recovery. About 650,000 houses, mostly of mud and straw, have been partially or completely washed away and more than 5,300 miles of roads have been damaged." -- August 13 "All of the country's major rivers have burst their banks for the second time since late July, with the waters destroying everything in their path on the way to the Bay of Bengal" -- August 26 "Officials estimate more than one fourth of the 55,126-square-mile country is under water and that 2.3 million acres of cultivated land have been destroyed by the floods.
C. China	07/02/ - 07/23/	56	25,600			386,000 ha	268,100	Reports from the provincial water resources and electric power department warn, the water level of the chuhe river, a major tributary of the Yangtze river, reached a record high on July 7, while the flood level of The huaihe river surpassed the danger level at the border of anhui and henan provinces on the morning of July 8.
C. China	06/24/ - 07/02/					534 square miles	139,900	The official newspaper said violent storms battered central Sichuan Province beginning June 24, with more than 19 inches of rain falling over two days Before the storms struck, the farming area had been in the grip of its longest drought in 40 years. Official's say China may face unusually bad flooding this summer because of a long period of abnormal weather.
1988								
China	09/05/ - 09/14/		100,000		Continuous heavy rains	200,000	47,800	Continuous heavy rains have severely waterlogged the donating lake area, one of the country's prime agricultural and commercial bases. Twenty-three counties and cities in hunan and hubei provinces have been affected. The inland lakes have overflowed flooding nearly 200,000 hectares of farmland. More than 100,000 people have been evacuated
NE. India and Nepal	08/23/ - 09/15/		42,901			Hectares of crop area in Assam -- 1,700,000 hectares in Uttar Pradesh	626,900	8/24 "the flood situation in india's northeastern state of assam further deteriorated today following alarming rise of the mighty brahmaputra river and its tributaries in the entire 800-kilometer-long brahmaputra valley from dibrugarh to dhubri" -- 8/29 " the brahmaputra river, in spate, wrecked havoc in santipur, bhutnath, fatasil and ambari areas. The entire brahmaputra valley was virtually in the grip of unprecedented floods." -- 9/5 "one hundred and eight people have been killed by floods and landslides caused by torrential rains at different districts in Nepal, according to the home ministry. This year's floods also damaged roads, bridges, canals, drinking water projects, culverts and public and private houses, causing a heavy loss of property to Nepal," -- 9/5 "the flood situation in India's northeastern state of assam deteriorated again on Sunday with the brahmaputra river maintaining a rising trend, it was reported here today. Official reports from guwahati, capital of assam, said the brahmaputra was rising rapidly in dibrugarh following heavy rain in its catchment in the lower region on Sunday. While vast areas of dubri and goalpara remained submerged in lower assam the situation in other districts of upper assam continued to improve."
Bang.	08/20/ -10/03/	1378	28,000,000	2,000,000,000	Unusually strong monsoons	4,700,000 hectares -- two thirds of Bangladesh inundated -- 2.5 million acres of crops	138,900	"The floods destroyed an estimated 3.5 million tons of standing crops and stored grain. It washed away 2,200 miles of roads and razed eight million houses." -- "SINCE 1 SEPTEMBER MORE THAN HALF OF BANGLADESH REMAINED FLOODED. 20 MILLION PEOPLE NOW AFFECTED IN 39 DISTRICTS." -- Sep 7 "NEARLY 600,000 COMPETELY DESTROYED HOMES: 1.5 MILLION DAMAGED. TOTAL OF 30,000 KM ROADS PARTIALLY DAMAGED OR DESTROYED. RICE CROP ON 1.5 MILLION HECTARES DESTROYED AND SERIOUSLY DAMAGED ON 2 MILLION HECTARES. OFFICIAL ESTIMATESOF CROP LOSSES BETWEEN 1.5 – 3 MILLION TONS."
Bang	06/27/ - 08/15/	254	5,250,000	450,000,000	Monsoon flooding	3,000,000 acres	98,280	Roads throughout Sylhet and the surrounding districts of Sunamganj and Moulvibazar in the far northeastern corner of Bangladesh were also washed out or still under water. " -- July 16 "Officials at the Flood Control Ministry in Dhaka said today that water levels were receding in most flooded areas except Brahmanbaria and Manikganj" -- July 26 "swollen rivers are overflowing their banks all across northeastern Bangladesh
China	06/24/ - 06/28/	65	500,000	76,000,000	Flooding and storms	145,300 acres	33,860	Flooding and storms killed 65 people and injured 1,420 others in 36 counties of Sichuan province in late June, provincial officials said here today. In addition, 1,341 head of livestock, 145,300 hectares of crops, 100 small hydroelectric stations and thousands of houses were destroyed
NE. India	06/21/ - 07/14/	34	2,000,000		Incessant heavy rains	108,375 hectares in Assam	70,500	Meanwhile the mighty brahmaputra and its major tributaries have flooded the low-lying areas of dibrugarh, tezpur and neamatighat. In the low-lying areas of guwahati, capital of the state, people had to wade through waist-deep water in some places " -- July 7 "the flood situation in assam state worsened further on Wednesday with the brahmaputra and its several tributaries having past their danger mark and submerged vast areas in the upper region. Official reports received here said the rain-fed

								brahmaputra, which had already crossed its danger mark at neamatighat, inundated about 25 villages in jorhat sub-division
NE. India and E. Bang	05/23/ - 06/11/	India: 26 -- Bang: 50	India: 3000 -- Bang: 40,000		Melting snow from t Himalayas and pre-monsoon rains in Bang	India: "Thousands of acres" -- Bang: 200,000 acres in Sylhet district	42,290	A total of 1,418 villages with a population of 835,005 have been affected by flood in India's northeastern state of assam ... about 6,000 head of cattle and a vast area of paddy cultivation have been washed away in the flood-hit state" -- May 31 "A flash flood on the Kushiara River washed away an entire village of more than 200 people
1993								
China	07/27/ - 08/01/	41	7000	27,000,000	Three days heavy rain	3,000 ha	9500	The record rainfall cut off all access roads to Emei City, a popular tourist destination, when it dropped 21 inches (52 mm) of rain in as many hours and inundated the city's railway station with 5 feet (1.5 m) of floodwater.
China	07/03/ - 07/31/	Jiangxi: 42 -- Hunan: 129 -- Guangxi: 196	Jiangxi: 210,000 -- Hunan: 500,000 -- Guangxi: 293,000	Jiangxi: 205,000,000 -- Hunan: 175,000,000 -- Guangxi: 190,000,000	Rains, which fell from July 1-5. More rains in Hunan starting Jul 17	Hunan: 646,000 ha -- Guangxi: 65,000 ha	119,000	Jiangxi - "... several rivers in northeast Jiangxi to break their banks ... Nine towns with 210,000 residents were marooned by flood waters" – Hunan -"floods in central Hunan province had killed 78 people in 10 days" ... "some 72 counties, 1,555 towns and townships and 17,270 villages in the province were affected by floods" -- Guangxi - "the region experienced record torrential rains for five days in succession ... the hilly city of wuzhou at the confluence of xijiang, a tributary of the pearl river, xunjiang and guijiang rivers has suffered the most. Streets, markets, storage facilities and the port in the eastern part of the city are flooded
N. India, Nepal, Bang and Pakistan	07/08/ -08/13/	India: 1050 -- Nepal: 1800 -- Bang: 218 -- Pakistan: 15	India: 3,000,000 -- Nepal: 200,000 -- Bang: 6,000,000 -- Pakistan: 170,926	India: nd -- Nepal: 100,000,000 -- Bang: nd	Unusually heavy monsoon rain	India: 800,000 hectares -- Nepal: 24,000 acres -- Bang: 28,742 square km. 520,000 ha -- Pakistan: 798,315 Acres	531,500	India - "in the northern state of Punjab, where the heaviest rain in two decades left 16 people dead over the weekend, and flooded two-thirds of Patiala city and some 1,100 villages." -- July 24 "Nearly half of Bangladesh was under water Saturday after six days of relentless rain, and the death toll in four weeks of flooding throughout South Asia jumped to 2,100 people" -- Aug 13 "While floodwaters have receded from the plains of the north, India's heartland, parts of the northeastern state of Assam still remain inundated." -- Aug 29 - "Monsoon floods have begun subsiding throughout Bangladesh
E. China	06/15/ -07/08/	Zhejiang: 38 -- Jiangxi: 61 -- Hunan: 33	Zhejiang: 355,000 -- Jiangxi: 20,000 Zhejiang: 526,000,000 -- Jiangxi: 260,000,000 --		Heavy rains across eastern china between June 11 and 20 and continuing in early July	828,000 ha -- Jiangxi: 353,700 ha -- Hunan: 160,000ha -- Fujian: 4,700 ha	432,800	Zhejiang - "In some parts of Zhejiang province, a foot of rain has fallen since June 14" -- Jiangxi - "During that period, 187 millimeters (7.4 inches) of rain fell, quickly swelling rivers which flooded 353,700 hectares (873,600 acres) of farm land and destroyed 43,600 homes." -- Hunan - "most of central china's hunan province has been hit by heavy rainstorms since June 30" ... "in changsha, capital of the province, more than 3,000 houses in the western and southern parts of the city have been inundated." -- Fujian -"floods in the northern section of fujian province destroyed hundreds of houses, roads, bridges and irrigation works"
NE. India and Bang	06/04/- 06/22/	India: 18 -- Bang: 220	India: 700,000 -- Bang: 250,000	India: 28,600,000 -- Bang: nd		Bang: 150,000acres	259,000	India: "vast stretches of paddy fields have been inundated in the district as all the rivers are flowing at the extreme danger level. Road communication, train services and water and power supply were disrupted by the flash flood caused by incessant rains during the last few days"
1997								
S. Bang	03/19/ 97 03/24/ 97	25	5000		ITCZ convective rain or easterly wave			
1998								
Bang and NE. India	07/05/ -09/22/	2632	25000000	3400000000	Torrential monsoon rains	7,000,000 Ha (3/4 of Bangladesh is submerged)		
C. China	06/12/ -06/27/	40	400000	481000000	Torrential rain worst in 50 years in Changsha Xiangjiang exceeding record high level	130,000 Ha		
E China	06/12/- 06/28	51	434500	240000000	Torrential rains	500,000 Ha		
SW. China	06/18/ - 06/19/	27						
C. China	06/18/ - 07/13/	164	370000		Worst since 1991			
SW. China	06/27/ -07/13/	170	240000	312500000	Yangtze's highest in 6 years	85,000 Ha		
SE. China	07/17/ -08/05/	345	3120000	1310000000	Torrential rains continuing Yangtze flooding and major dyke break	1,320,000 Ha		
C. China	08/05/ -09/07	575	1115000	3710000000	Continued	1,320,000 Ha		

SW. China	08/03/ - 08/07/	90			Torrential rains and Yangtze headwaters			
SW. China	08/19/ -08/29/	19			Torrential rains			
Bang. NE. India	06/09/ -06/12/	77	2000					
China	05/20/ - 05/25/	58	106000	247000000	Heavy rain water level higher in some areas than in 1954	280,600 Ha		
China	05/20/	10	20000	10800000	Torrential rain such strong storms are rare hitting every 100 years	3,000 Ha		
China	05/20/ - 05/25/	8	15000			206000ha farmland		
Bang.	05/20/ 98 -				Tropical cyclone			
C. China	05/01/		2000		Torrential rain	8,000 Ha damaged		
SW. China	05/07/				Torrential rain	90,000 Ha		
C.E. China	03/06/ -03/13/	2	130000		Frontal storms record stage of 37.64 m in Changsha	'Large tracts of farmland 20000ha		Experts attributed the flooding in the middle and lower reach of the Yangtze to El Nino
1999								
E. India	10/29/ 11/12/	9,803	10,000,000	$2,300,000,000	A cyclone struck with tidal waves and heavy rains causing flooding worst flooding in 100 years	1.711 million hectares crops have been affected		Suitable AVHRR data located
India and NW. Bang.	09/24/- 09/29/	India: 41 Bang: 4		$235,000,000	Torrential rains and heavy storms...heavy monsoon floods	Bang: 17,000 hectares		
S E. Bang and E. India	08/11/ 08/15/	18	50,000		Heavy rains, flooding and mudslides.			No suitable AVHRR data located
C. China	08/12/ 08/16/	77	120,000	$181,000,000	3 days of flash flooding after precipitation reaching 295 mm in 24 hours	300 ha		No suitable AVHRR data located
Bang and E. India	07/11/ 08/03/	Bang: 31 -- India: 325	Bang: 310,000 -- India: 3,000,000		Monsoon Season during June and July -- Heavy rain	Homes and crops of 450,000 in Comilla District submerged. -- 48,000 Hectares crops submerged in Comilla		
Bang	06/21/ 07/06/	19	100,000		Torrential rain	60,000 hectares crops. – Jumuna River: 1,600 hectares farmland lost along and 5,000 hectares inundated		
SE. China	05/26/ 06/23/				Rainy season			
C. and SE.	05/18/ 05/21/		69,200		200 millimeters	300,000 hectares crops		

China					of rain since	damaged		
2000								
E. India and Bang	09/18/ 10/21/	India: 1,358 -- Bang: 110	India: 20,000,000 -- Bang: 4,000,000	India: 700,000,000 -- Bang: "several million dollars worth of property and crops have been destroyed"	Late monsoon rains that triggered flash floods Western Bangladesh:	West Bengal: 1,500,000 hectares	155,000	Flooding is common in the eastern India and Bangladesh at this time of year, but it is usually not as extensive or sudden." ... "Besides the flash floods triggered by incessant torrential storms, the disaster is also man made. Sluice gates of at least three dams were opened to stop the water barriers from bursting. This not only worsened the situation in West Bengal but the overspill of water entered the neighboring Bangladesh rendering nearly 100,000 people homeless" ... "The floodwaters have drowned much of the Indian-Bangladesh borders under 10 feet (3 meters) of water." -- Bangladesh: "The week-long floods have inundated the country's 10 western border districts, spared from devastating floods in 1998 when more than 1,200 people died.
NE. India N. Bang Bhutan Nepal	08/02/ 08/29/	India: 300 -- Bangladesh: 31 -- Bhutan: 200 -- Nepal: 106	India: 4,000,000 in Assam 5,500,000 in all India. -- Bangladesh: 1,000,000 -- Nepal: 4,000	India (Assam province): $50,000,000 -- Nepal: millions of rupees Flooding triggered by monsoon rains		Assam: 300,000Ha	324,400	In all countries involved, landslides accompany the flooding. -- India: "The Assam government has sounded a maximum alert with the Brahmpautra flowing at least five meters (16 feet) above the danger mark." -- "In all, 3,568 villages in 16 districts have been inundated and crops in more than 197,031 hectares damaged. More than three million people have been affected by the floods." -- Bhutan: "the landslides blocked nearly the country's entire road network" – August begins to recede in Assam. -- Sep 5 Eastern India - "The floods are receding in places and people have gone back to their homes. But there are large pools of stagnant water surrounding people's homes where water-borne diseases could proliferate"
China	06/30/0 7/27/		Hubei: 12 -- Sichuan: 18 -- Shaanxi: 35 Hubei: 60,000 -- Sichuan: 3000 -- Henan: 25,000	Hubei: $55,000,000 -- Sichuan: $16,000,000 -- Shaanxi: $12,000,000 (Ziyang only)	Torrential rains causing flooding and mudslides	Hubei: 38,145 hectares. -- Sichuan: 35,000 hectares. -- Shaanxi: 119,000 hectares. -- Henan: 86,000 ha.of farmland	108,000	Yangtze River first flood crest of the season passed Yichang City site of Three Gorges Dam (news report dated July 6) -- ~200 people in Shaanxi province were killed 07/10 - 07/11/00 in rain-triggered landslides.
Bang	06/19/ 06/25/	Northern: 14	Northern: 20,000		Monsoon rains		17,000	150 mud-thatch huts swept away by the Darala River, "At least 30 villages have been submerged in the Kurigram district, 240 kilometers north of the capital, Dhaka, according to the Flood Warning Center in Dhaka", 237 millimeters of rain recorded in 4 days -- No suitable AVHRR or Landsat7 data located
E. India	06/10/ 7/10/	30	50,000		Intial flooding on June 11 caused by breach of landslide-blocked river near Yigong,	11,000 Ha	55,000	"worst flood to hit Arunachal Pradesh since 1959" -- June 26"The United News of India reported that the floods have inundated 250 communities in six districts and affected almost a quarter of a million people. " -- "Preliminary findings suggest the floods in Arunachal Pradesh were due to the breach of a dam on the Tsangpo, as the river makes a turn to enter India" – On April 9 a large landslide occurred that blocked the Yigong Zangbo River (a Bramaputra tributary) in eastern Tibet. A lake formed behind the earth dam which was breached on June 11, causing the flash floods downriver in Arunachal Pradesh, India
2001								
C. China	06/19/ 06/23/	66	10,000	120,000,000	Seasonal rains		3600	"About 281 mm of rain fell in 10 hours over Suining causing mudslides in the mountainous area. More than 2,400 houses were destroyed while 250,000 livestock perished"
C. China	06/19/ 06/23/	66	10,000	120,000,000	Seasonal rains		3600	"About 281 mm of rain fell in 10 hours over Suining causing mudslides in the mountainous area. More than 2,400 houses were destroyed while 250,000 livestock perished"
NE India and Bang	06/05/ 06/22/	India: 5 Bang: 13	India: 700,000 Bang: 100,000		Heavy monsoon rains.		17,560	"The authorities have sounded the red alert in the states of Assam and Tripura where all major rivers have been swollen by incessant rains" "India's northeast state of Tripura, which was hit by heavy flood, remained cut off from the rest of the country for the third day Friday ... In the neighboring state of Assam, the situation was even worse with more than 200,000 people of nearly 100 villages in the southern part of the state affected" "Nearly 400 millimeters (16 inches) of monsoon rains not unusual for this part of the year have lashed Bangladesh's northeast since early this week. "
2002								
NE India and Bang	06/21/ 07/15/	88	2,300,000		Monsoon rain	170,000	276,600	
C. China	06/23/ 07/12/			120,000,000	Rain		600,000	
C. China	06/15/ 06/23/	53	32,000	50,740,000	Rain	476,000	130,300	
NE India and Bang	06/12/ 06/21/		25,000		Rain		15,670	
C. China	05/22/ 05/28/			943,000,000	Rain	590,000	156,100	
E. Bang.	04/18/ 04/28/					19,275	4,850	

4 Parameters for risk monitoring, early warning and forecasting of floods

4.1 Parameters for risk monitoring, early warning and forecasting of floods

Flood-forecasting techniques include four main components:

- Forecasts of meteorological parameters: Rainfall, Intensity, Timing, Duration
- Hydrological process models: Meteorological and hydrological inputs, Depth and Discharge, Downstream flow as output
- Mathematical hydraulic models: Description of river channel, characteristics of the flood
- Combination models

Meteorology is the study of the atmosphere and its phenomena. Weather and climate deal with the spectrum of these phenomena on different space and time scales. Weather systems are related from one region to another, and similar climate zones extend beyond national boundaries. In order to understand the climate and to predict the day-to-day weather, meteorological data from neighboring countries and all regions of the world are needed. In order to have country-to-country cooperation, the International Meteorological Organization (IMO) and the World Meteorological Organization (WMO) were established to cater to the need for exchange of meteorological data between countries. Standardization of instruments, observational procedures and archival of data were the cornerstones in the development of meteorology. Members of WMO developed plans and programmers to facilitate worldwide cooperation in the establishment of networks of observing stations for making meteorological, hydrological and related observations, and ensuring their rapid exchange. WMO launched the World Weather Watch (WWW) system in 1963. It operates on a 24-hour basis through the integrated efforts of the network of National Meteorological Service (NMSs) of all WMO Member countries. WMO coordinates data collection and exchanges from 10,000 land based stations, 1,000 upper air stations, 3,700 ships, 300 moored buoys, 600 drifting buoys as well as 3,000 aircrafts which provide over 7,000 additional observations on daily basis (Figure 4.1-1).

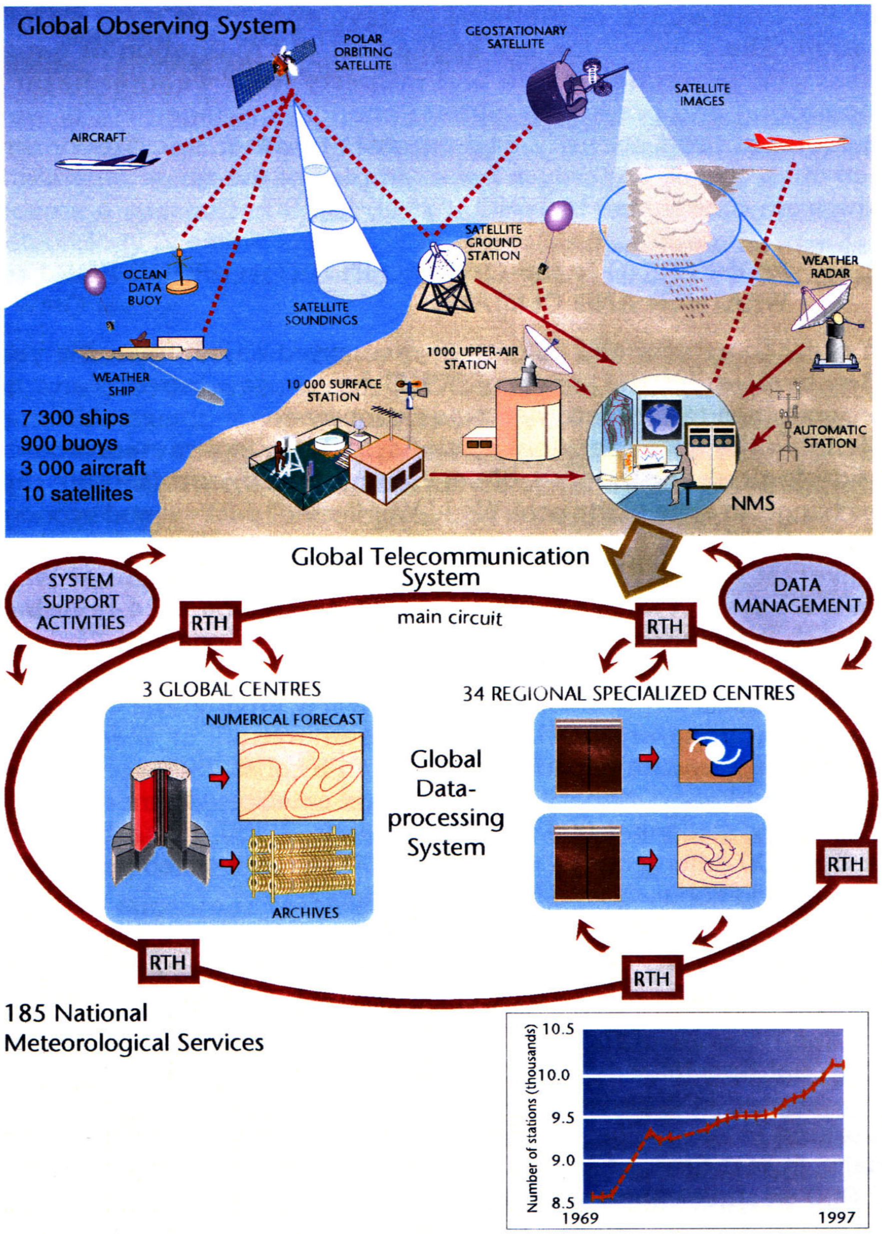


Figure 1 — Global Observing System. Exchange of data and distribution of weather/climate products and information have been made possible by means of national regional and global communications networks. Inset: Development of landsurface station network

Fig. 4.1-1 Global Observing System (Source: WMO, 2001)

4.2 Data requirements

Data requirements for flood forecasting models include:

- Hydrological data: Stream-flow measurements and peak flow measurements
- Meteorological data: Rainfall intensity and duration, precipitation forecasts, and past data for rainfall-runoff models

- <u>Topographic data:</u> possible extent of inundation and watershed size
- <u>Geological / soil data</u>
- <u>Demographic data</u>
- <u>Land cover / land use data</u>
- <u>Reservoir management principles</u>
- <u>Post-flood damage assessments</u>

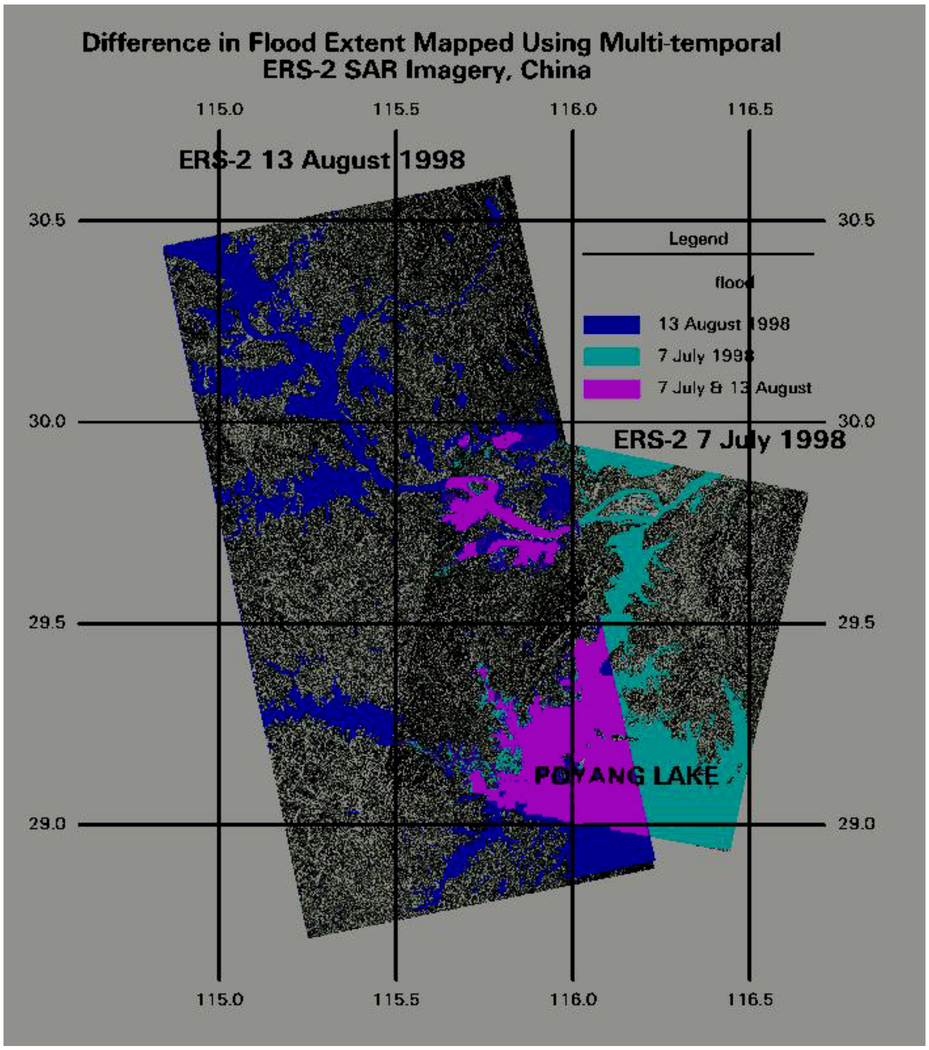


Fig. 4.2-1 Flood in Yangtze River of China. The image covers the flooded area around Poyang Lake and the Yangtze River. Ascending and descending ERS-2 SAR passes acquired on 7 July and 13 August 1998 are shown. (Source:ESA 2002).

5 Review of methodologies in developed countries

Considering the loss of lives and property from any natural disaster, people benefit from prior information about the natural disaster. Some natural disasters are complex and their causes are not exactly known, so prior information is limited. The probable causes of floods are known but the parameters that control floods are dependent on numerous factors. These parameters are complex and their behavior is also complex. Accurate, timely prediction of the possible occurrence, location and magnitude of a specific flood can reduce loss of life and property. The forecast requires understanding of meteorology, hydrology and hydraulics. Flood experts have made efforts to integrate knowledge in these three fields to predict or forecast floods (Changnon, 2000).

With the help of numerous satellites in space and remote sensing techniques, various countries and international agencies are developing early warning systems. Contrasts between flood forecasts and early warning efforts in developed and developing countries are identified below.

5.1 History of Flood Warnings

The Romans used dams and diversions in attempting to reduce potential floods and to manage water resources. Concerns about floods have existed in United States since the first settlers came to New World. Early efforts to reduce flood related deaths and damages, however, were primarily devoted to flood control measures such as levees, dams, and storage reservoirs. Flood warning systems were not feasible until suitable communication systems were developed.

Early flood warning systems for people living along streams undoubtedly involved personal travel and verbal exchange of information. Communication systems such as the telephone greatly improved the timeliness of flood warnings. Federal, state and local water management agencies began to remotely access data from USGS gauging stations in the 1930s using an instrument called Telemark. When accessed by telephone, Telemark transmitted a river stage by a series of beeps or rings. Very high frequency radio also began to be used in the 1930s to obtain river stage data. By the 1950s river stages could be accessed at hundreds of USGS gauges throughout the U.S. to forecast floods, provide flood warnings, and for water management purposes.

The continued evolution of communication and stage sensing equipment has further improved data access for flood warning and flood forecasting purposes. The principal device currently in use is a gauge for obtaining near real time for flood warning or other water management purposes. Another device transmits data via satellite to a receiving station, where the data are then relayed to equipment with conventional radio and telephone systems. This contributes to the timeliness of data critical for warning or water management purposes.

The initial use of remotely accessed data to forecast floods was often limited to the interpretation of correlative relations that existed between different streams or streams locations, which required a great deal of intuitive expertise and knowledge on the part of the river or weather forecaster. The rapid development of more sophisticated computer systems since the 1970s, however, has permitted large amounts of data to be incorporated into computer simulations models for more accurate and timely forecasting.

5.1.1 From 1970s to 1990s

Numerous researchers have laid down the foundations of a scientific approach to flood warning systems during the 1970s and early 1980s. They have culminated in a decision-theoretic methodology for modeling and evaluating forecast-response systems for floods on main-stem rivers (Krzysztofowicz and Davis, 1983), a comprehensive set of design requirements for flash flood warning systems (Georgakakos, 1986), and development plans for improving hydrologic services to the Nation (NWS, 1982; Hudlow, 1988).

The revived interest in warning systems as a means of reducing negative consequences of floods and a viable alternative or an addition to traditional structural flood controls such as dams, levees and diversion channels, stimulated new research activities in the last four decades. This research has three prongs: (1) a multi-objective decision technique which offers a tool for planning and operating flood warning systems, (2) a Bayesian theory has been formulated for comprehensive studies of local flood warning systems, and (3) several applications of the Bayesian theory.

<u>A Multi-objective Technique</u>

The classical method of computing the expected annual flood damage, based on a stage-damage function and a probability distribution of the annual flood peak, has been extended by Haimes et al. (1994). The extension includes a calculation of the expected annual damage along with solutions that combine structural flood controls and a warning system. In a case study, four alternative plans have been compared: do nothing, construct levees, install a warning system, construct levees and install a warning system. The comparison was based on three criteria: average annual cost, expected annual flood damage, and restricted expectation of the annual flood damage caused by peaks higher than the T-year event (T = 10 and T = 100). This methodology is important in that it places the flood warning system on a par with structural measures and demonstrates how methods used by the U.S. Army Corps of Engineers in project feasibility studies can be supplemented with a formal multi-objective analysis.

Under the assumption the decision rule for issuing a flood warning is of the threshold type (i.e. a warning is issued whenever the forecasted flood crest exceeds a threshold), Haimes et al. (1990) proposed a model for selecting the threshold. Imbedded in the model are four postulates: (1) the threshold currently in effect should be a function of the fraction of people in the community who responded to the previous warning, (2) this fraction decreases after a false warning and increases after a detection, (3) A fixed number of future events (marked by floods and false warnings) should be considered when selecting the threshold, (4) the selection should be Pareto-optimal with respect to the maximization of three objectives: the expected property damage reduction in the course of all events, the expected life loss reduction in the course of all events, and the expected fraction of people who will respond to the warning after the last event. A weighting method in conjunction with dynamic programming has been used to find solutions in a case study (Li et al., 1992).

The approach leaves unanswered several methodological questions. Two of them point out the possible research directions. (1) Why is it desirable, from either the normative or the behavioral point of view, to change the warning threshold after each event? Since such a change alters the probabilities of detection and false warning, the reliability of warnings becomes non-stationary and the public can no longer rely on experience to learn appropriate responses. (2) How should one choose the number of events (stages) for the dynamic programming? Since the probabilities of detections and false warnings remain unknown until a realization of thresholds is observed, a fixed number of events does not determine the length of time over which these events occur, and thus one cannot apply the usual notion of a planning horizon.

A Bayesian Theory

The theory, which derives from Bayesian principles of rationality, offers a methodological framework and mathematical concepts for modeling warning systems in communities exposed to flash floods or rapid river floods. Models may be used (1) to develop optimal decision rules for issuing warnings, (2) to evaluate system performance statistically, and (3) to compute the expected economic benefits from a system (Krzysztofowicz, 1993a).

A flood warning system is decomposed into a monitor, a forecaster, and a decider. The monitor is characterized by the diagnosticity and reliability parameters. Floods are characterized by a prior distribution of the crest height and time to crest; the forecaster is characterized by a family of likelihood functions of the actual crest, conditional on the forecasted crest. The decider is characterized by a disutility function that quantifies the relative undesirability of outcomes (such as response cost, property damage, lives lost) and whose expectation provides a criterion for decision-making. Given these inputs, the theory provides three principal outputs: (1) an optimal warning rule, which prescribes whether or not to issue a warning based on an imperfect forecast of the flood crest, (2) a relative operating characteristic, which shows feasible trade-offs that a given system offers between the probability of detection and the probability of false warning, and (3) utilitarian measures of performance: the annual value of a given warning system, and the potential annual value of a warning system for a given floodplain.

The models of the monitor and the forecaster quantify all uncertainties associated with operation of the warning system, from the viewpoint of a decision maker. At the heart of this quantification is the Bayesian processor of forecasts (BPF) that outputs a posterior description of uncertainty about flood occurrence and crest height, conditional on a flood crest forecast.

One of the formidable challenges in applying the BPF in this and other contexts has been modeling of likelihood functions and derivation, or computation, of the posterior distribution when the prior distribution is not a member of the conjugate family for a specified likelihood model. Apart from the convenient normal-linear BPF, there are virtually no suitable analytic models. This has been a major hurdle in applying Bayesian methods to forecasts of flood peaks whose distributions are anything but gaussian. A general analytic solution for the BPF has been found: the posterior distribution can be obtained for any prior distribution, parametric or nonparametric (Kelly and Krzysztofowicz, 1994a).

Applications of Bayesian Theory

The reliability of a flood warning system can be characterized statistically in terms of two measures: (1) the relative operating characteristic (ROC), defined earlier, and (2) the performance trade-off characteristic (PTC), which shows feasible trade-offs that a given system offers between the expected number of detections per year and the expected number of false warnings per year. When the floodplain extends across a range of elevations, the ROC and PTC are defined for each zone of the floodplain (Krzysztofowicz, 1992b).

Numerical procedures for computing the ROC and PTC have been derived and applied to flood warning systems serving three communities in Pennsylvania. The case of Milton demonstrates fundamental trade-offs between the reliability and the expected lead-time of warnings. The case of Connellsville demonstrates synergistic gains in warning reliability due to a coupled solution: a flood warning system and a flood control dam upstream (Krzysztofowicz et al., 1994).

In order to synthesize information for strategic planning and policy decisions, envelopes of ROCs have been constructed; they display graphically the overall reliability of flood warning systems within a region. A case study presents ROC envelopes of warning systems for uncontrolled rivers in Pennsylvania from 1960-1980 (Kelly and Krzysztofowicz, 1994b).

Finally, the BPF has provided a framework for studying the synergistic effect of a dam and forecasts. In essence, the dam changes not only (1) the natural regime of flood flows (and hence the prior distribution in the BPF), but also (2) the predictability of flood flows (and hence the likelihood function in the BPF). These changes affect the posterior probability of flood occurrence and the posterior distribution of the flood crest. These effects have been illustrated with a case study (Kelly and Krzysztofowicz, 1994c).

5.1.2 Artificial Neural Network Model

The ANN model has been designed with the capability of real-time updating so that the estimates can be improved using ground based observations from various sources. Currently, rainfall estimates computed by the NEXRAD system (composite with older radars to provide full coverage of the continental U.S.) are being used for testing and evaluation. NEXRAD reflectivity data and SSM/I microwave data are provided by the Global Hydrology Resource Center (GHRC) at the Global Hydrology and Climate Center, Huntsville, Alabama. http://microwave.msfc.nasa.gov/

The CD-ROM contains one full year (August 1, 1998 through July 31, 1999) of tropical surface rainfall-rate estimates for the oceanic and continental region encompassed by 80E-10W longitudes and 35S-35N latitudes. The remotely sensed data from multiple satellite sources-three geosynchronous satellites (GOES-8, GOES-10, and GMS-5) and the EOS/TRMM satellite-by the PERSIANN system (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) (Hsu, et al., 1997; Hsu et al., 1999) were developed at the Department of Hydrology and Water Resources, The University of Arizona. This data set is designed for use by various groups, including large-scale climate, weather and hydrology communities. In particular, the data was processed at spatial and temporal resolutions compatible with atmospheric modeling, with the intention that both the modeling and analysis communities can use it in investigations of the evolution of tropical/subtropical rainfall systems, their inter-annual, inter-seasonal and diurnal variations, the difference in rainfall over oceans and over land, and the transition from the 1998 El Niño to the 1999 La Niña. This data set (Version 1.0) represents a first effort to implement the PERSIANN system into the development of an operational global-scale database. This version omits the use of GOES daytime visible imagery in conditioning the estimates, and does not give special consideration to explicitly discriminating between retrievals over land, coast and ocean (Sorooshian et al., 2000). Further, the regions covering Africa and India (Meteosat) are not included. Extensions of the data set are ongoing, and Version 2.0 is expected to incorporate these and other improvements, such as information about the uncertainty of the estimates. However, the rainfall-rate estimates provided in this data set have been extensively evaluated by comparison with ground-based observations (gauge, radar) and with TRMM rainfall products (Sorooshian et al., 2000).

5.2 Flood prediction in the U.S.

Floods in the U.S. caused over $30 billion in damages between 1993 and 1997, more than any other natural hazard (Changnon, 2000). In the U.S., loss of life from floods is third after temperature extremes and lightning (Changnon et al., 1996). Floods create long-lasting effects on the economic productivity of any country as well as on the health of its people.

The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) is the federal agency in charge of weather forecasts and warnings for the nation. NWS is also charged with the responsibility of issuing forecasts and warnings of floods. Flooding caused by rainfall along major rivers takes many hours and even weeks to develop. Floods caused by snowmelt runoff may take months to develop. Flash floods occur when intense precipitation falls during a brief time span on smaller rivers; the time between the onset of intense precipitation and the cresting of the river during a flash flood is hours instead of days. More than 10,000 precipitation and stream flow stations, including more than 3,000 stream flow gauges operated by the USGS, provide hydrologic data to NWS offices across the country for use in the flood-forecasting program. Hydrologic data collection at stream gauging stations is telemetered through the Geostationary Operational Environmental Satellite (GOES) to regional data centers.

The NWS routinely issues flood forecasts for approximately 4,000 locations in the United States. The NWS has responsibility for issuing storm warnings, display of weather and flood signals for the benefit of agriculture, commerce, and navigation, and gauging and reporting of rivers. To develop flood forecasts, the NWS relies on a number of other federal agencies to achieve its mission, particularly the USGS and the Army Corps of Engineers (COE; the Corps). Within the NWS, the Office of Hydrology has responsibility for collection and processing of hydrologic data for river and floor forecasts (Stallings and Wenzel 1995. The NWS also is home to five regional hydrologists who have expertise on flood threats in different parts of the nation. Figure 5 shows the organization of the NWS Office of Hydrology as of the mid 1990s.

In order to monitor the river systems, the NWS operates 13 River Forecast Centers (RFCs) across the nation, each centered on at least one major river basin. The RFCs provide flood information to NWS Forecast Offices, where the information is distributed to city, county and state officials as well as to the public. About three thousand communities are served by the 13 RFCs, each of which has a staff of about 16 (Stallings and Wenzel, 1995). In periods of normal river flows, RFCs produce stream flow forecasts for large operations as well as water management decisions for applications such as electric power generation. RFCs also work with local communities to help them better prepare for floods and flash floods.

The process of the development of a flood forecast for public dissemination typically involves three steps:

- Observations (precipitation, temperature, etc.) to estimate the net amount of water entering the (river) basin from rainfall and/or snowmelt
- The net input of water (from rainfall or snowmelt) into a volume that enters the stream (runoff)
- The volume rate of water (discharge) that flows from a point in the stream to points farther downstream

5.2.1 Hydro-meteorological Data

Stream flow data is an essential component of flood forecasting. The stream-gauging program of the USGS is the largest national program responsible for the collection and dissemination of stream flow data. This effort is supported by more than six hundred federal, state, and local agencies and organizations. In 1994, only 549 stations (of more than 7,000 total) were funded solely by the USGS. The Natural Resources Conservation Service, Salt River Project, Tennessee Valley Authority, and NOAA are important contributors to the collection of stream flow data. The USGS opened its first stream-gauging station in 1889 on the Rio Grande River and by 1994 operated a total of 7,292 stations throughout the country. Of these stations, about 3,000 contribute data used by the NWS to forecast floods. In addition to flood forecasting, the stream-gauging program collects data that are used in water resources planning, hydrologic research, and the operation of water resources projects (such as dams).

Stream flow data are also collected through the NWS hydrologic network of about 11,000 private citizens. Some of these volunteers report river and rainfall information to their local Weather Service Office or Weather Service Forecast Office on a daily basis. This information is tabulated and communicated to the appropriate RFC for use in river and flood forecasts.

The spatial and temporal records of stream flow in the U.S. expanded throughout the twentieth century for a number of reasons. Early in this century, irrigation and hydroelectric power needs created demand for stream flow information. The extensive drought of the early 1930s, followed by extreme flooding later in that decade in the Ohio and Potomac river basins, created a demand for better understanding of extreme low- and high-water flows on major rivers. Also, the continental U.S. contains more than 846,000 drainage basins that are between one and two square miles in size and in the 1950s, the establishment of the Federal Interstate Highway system created a need to estimate potential flood flows at the many locations where interstate highways pass over small streams and drainages. Finally, the establishment of the National Flood Insurance Program in 1968 created a demand for data on floodplain mapping and flood frequency. The stream-gauging program developed incrementally over the past one hundred years. Today, it provides valuable data for flood forecasts and other water resources-related uses. Data collected through the stream-gauging program includes the stage of a river to find out the height of the water surface above a reference elevation, which is important for mapping of flood plains. For flood forecasts, discharge of rivers is important. The discharge is defined as the volume of flow passing a specified point in a given interval of time and includes the volume of water and any sediment or other solids that may be dissolved or mixed with the water. Discharge is typically expressed in cubic feet (or cubic meters) per second and is often determined through direct measurement or through a statistical relation with the stage level. Discharge is a fundamental input to hydraulic models. The relationship between river stage and discharge for a specific location, determined empirically, is known as the rating curve. Using a rating curve, one can easily convert between stage and discharge.

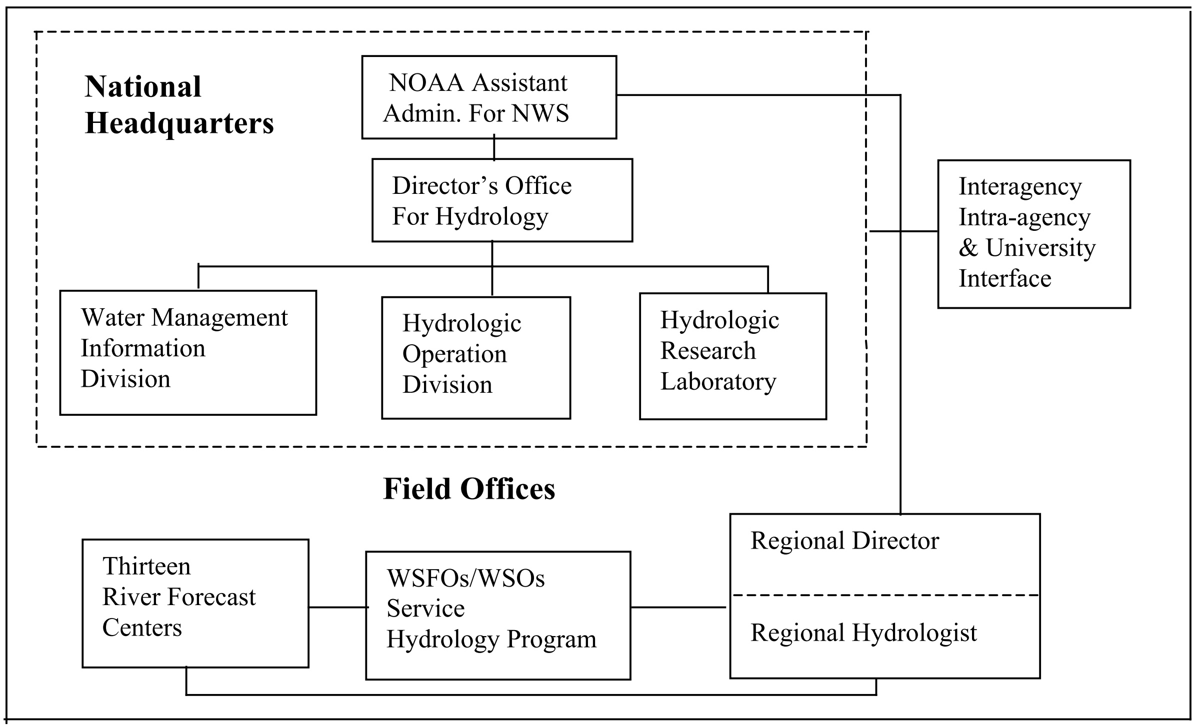


Fig. 5.2-1 Flow chart of National Weather Service's office of Hydrology

5.2.2 National Weather Service River Forecast System

The river Forecast Centers use a set of hydrologic models called the National Weather Service River Forecast System (NWSRFS) to turn raw data into flood forecasts. The NWSRFS provides a number of different procedures and models to characterize snowmelt, rainfall and runoff, runoff distribution, and channel routing to the hydrologists to develop a flood forecast (Larson et al., 1995). Hydro-meteorological data are used into hydrological models in order to produce flood forecasts. In areas where snow has accumulated, the forecast must combine outputs of a snow model, a soil moisture model, and a flow model. A snow model takes precipitation and temperature data as input and sends its output (melt + rain) to a soil moisture model. In addition to the snow model output, the soil moisture model also uses as input data on soil type, slope, land use, season, vegetation, and other parameters. The output of a soil moisture model is a calculation of runoff from a particular drainage basin. Runoff is described using the observed relationship between precipitation (or melt) and discharge over time for a particular drainage basin. Finally, a flow model is used to combine runoff from different headwater basins where they flow together.

The flood forecasts would benefit from improvements in quantitative precipitation forecasting (QPF), a technique that predicts the amount of precipitation that will fall over a particular area over a given period. The goal of using QPF in the flood forecasting process is to provide a longer lead-time for flash flood (i.e., floods that occur within a twelve-hour period or less on the upstream branches of a river basin) and river stage forecasts. Of course, the potential success of this tool depends in large part on the ability to forecast reliably the amount of precipitation that will fall over a particular watershed. The effective use of QPF has not been fully achieved. Studies of the use of QPF show benefits to decisions associated with flood warning, reservoir control, and commercial navigation (Krzystofowicz 1995). In recent years, flood forecasts have improved with the use of advanced radar technologies to identify in real time (as well as to forecast) areas of heavy rainfall, development of more accurate rainfall-runoff models, and improved collection of field data (Krzysztofowicz 1995).

5.2.3 Recent advances associated with flood forecast and warning systems (University of Virginia, Charlottesville)

Flash Flood Forecast

a. Rainfall-Runoff Models

Various problems associated with forecasting flash floods caused by convective storms over semi-arid basins have been studied by Michaud and Sorooshian (1994). Using data from 24 storms which occurred over a 150 km basin instrumented with 8 rain gauges and 10 stream gauges, a comparison of the performance of three rainfall-runoff models has been made: (1) a simple lumped model, (2) a simple distributed model (both using unit hydrographs), and (3) a complex distributed model (using kinematics equations). Based on mean square error of simulated peak flow, time to peak, and runoff volume, the lumped model was outperformed by both distributed models, which performed equally well. These results corroborate the known precepts (1) that the spatial distribution of rainfall is an important predictor of flash floods, and (2) that the law of diminishing gains does apply to complexity of hydrologic models. The complex distributed model was used next in a simulation exercise, where the runoff hydrograph was computed based solely on rainfall observed up to the forecast time, and a flood warning was declared whenever the computed flood crest exceeded a threshold. Computations were repeated at 15-minute intervals. After 24 flood events, the estimates of the warnings (probability of flood, given warning) and the reliability of warnings (probability of warning, given flood) were found equal to 0.71, and the average lead times of warnings ranged from 30 to 75 minutes. Michaud and Sorooshian (1994b) have confirmed the obstacles in flash flood forecasting: (1) even a relatively dense rain gauge network (one gauge per 20 km) may be insufficient to detect convective rainfall and estimate its spatial coverage and depth, and (2) without rainfall predictions, the reliability and lead time of warnings are severely constrained. The effect of the rain gauge density and rainfall sampling frequency on the accuracy of the computed hydrograph dimensions (crest height, time to crest, and total runoff volume) has been investigated by Krajewski et al. (1991) via a Monte Carlo simulation. A stochastic model of convective storms generated rain, while a distributed rainfall-runoff model with high spatial resolution (one rain gauge per homogeneous area of 0.1 km) and high rain sampling frequency (every 5 minutes) was assumed to generate the true runoff hydrograph from 7.5 km rural catchments. Against true hydrographs, hydrographs from four less refined models were compared, having one gauge per 1.5 km and 7.5 km, and sampling rainfall once per hour. Based on errors of the hydrograph dimensions, the authors concluded that the model performance was sensitive more to the frequency of rainfall sampling (5 min versus 1 hour) than to the density of rain gauges (one per 0.1 km versus one per 7.5 km). Only four cases of density-frequency parameters were investigated, precluding the generality of the conclusion. But if this is a general law, then it holds a message for forecasters: concentrate limited resources not on forecasting point precipitation, but on forecasting spatial averages and timing of the precipitation.

b. Rainfall Estimates from Radar

Some major advances in both theory and operations have been made by new technology: Weather Surveillance Radar 1988 Doppler (WSR-88D). Known as the Next Generation Weather Radar (NEXRAD) system, a network of about 160 of these radars were deployed by the NWS during the 1990s to cover all contiguous states. With a rainfall detection range of about 230 km and an array of products generated from the return signal, these radars are changing the view of operational forecasters on detection of local storms, estimation of rainfall coverage and intensity, and ultimately forecasting headwater floods and flash floods.

Potential gains from using weather radar in flood forecasting have been studied by James et al. (1993). A distributed rainfall-runoff model was applied to a 785 km basin equipped with two rain gauges and covered by radar. Data recorded during a past storm have provided inputs for computing three flood hydrographs from (1) rainfall recorded by rain gauges, (2) radar estimates of rainfall, and (3) combined rain gauge measurements and radar estimates. The hydrograph computed from the combined input was closest to the observed hydrograph.

c. Rainfall Prediction from Radar

The second benefit of weather radar derives from an observation that the trajectory of storm dynamics (velocity, azimuth, and intensity) estimated from subsequent radar scans may contain predictive information. Thus, even a short-term (0 - 3 hours) prediction of the precipitation field may be informative. Such a prediction offers the potential for better flash flood warnings.

In the 1980s, research concentrated mostly on estimation of rainfall rates from radar reflectivity and on prediction of rainfall rates through projection of trends detected in a time series of reflectivity fields. Some of these efforts were reviewed by Chen and Kavas (1992), who introduced a radically new technique. Harnessing concepts from pattern recognition theory, the technique decomposes the radar image of the rain field into constituent polygonal contours, whose evolution in time and space is tracked through subsequent radar images and then projected into the future via an adaptive exponential smoothing scheme. By recomposing the projected contours at a desired lead-time, a prediction of the rain field is obtained. The technique was validated for lead times up to 30 minutes on historical radar data from one storm with encouraging results.

d. Rainfall Prediction from Multiple Sensors

The bulk of research in the last four decades centers on integrating radar data with data from other remote sensors, such as satellites, radiosondes, and ground stations, into predictive models of rainfall. The framework for integration has been a mathematical model describing the physics of the convective precipitation process.

The potential utility of radar reflectivity as an additional input to a physically based spatially lumped rainfall model was explored by Georgakakos and Krajewski (1991). Their model was intended for making predictions of mean aerial rainfall over river basins of the order of 100-1000 km, with the lead-time of one hour. A comparison of forecast error variances obtained with and without radar data indicated that a reduction of 5-15% in variance could be attained.

Seo and Smith (1992) have formulated a two-component model for prediction of convective rainfall under the radar umbrella. The principal assumption is that the vertically integrated liquid water, as a function of time and space, is equal to the sum of a time-varying mean and a residual that varies in time and space. A physically based model predicts the mean using radar data, surface measurements of temperature, dew point temperature and pressure, and radiosonde profiles of environmental temperature and water vapor density. A statistical autoregressive model predicts the residual. Validation was limited to seven historical storms that also provided data for parameter estimation. Rainfall fields estimated from radar reflectivity have been assumed to be the ground truth. Predictions have been made every 10-12 minutes, for one hour ahead and an area of 80,000 km. Based on the mean square error criterion, the model forecasts outperformed, though not substantially, the advection forecasts (obtained via a translation of the current rainfall field, estimated from radar data at the forecast time, by the mean velocity vector one hour into the future).

Another predictive model was developed by French and Krajewski (1994). The model rests on the conservation of mass and momentum laws in which states and boundary conditions are parameterized directly in terms of radar reflectivity (a predictor of liquid water content) satellite infrared brightness (a predictor of cloud top temperature), and surface air temperature, dew point temperature and pressure. For applications, state dynamics are linearized and states are updated based on sensor measurements via a Kalman filter. In a verification study, reported by French et al. (1994) using historical data from three storms, predictions of the rainfall rate were computed every 10-15 minutes for the lead-time of one hour and an area of 170,000 km. According to the mean error, mean square error, and the correlation between forecasted and measured (via the same radar) rainfall rates, the model forecasts out-performed the persistence forecasts (obtained under the assumption that the currently observed rainfall will continue for one hour) and performed somewhat better than the advection forecasts.

Main-Stream Flood Forecast

a. Stream Flow Models

To forecast stream flow in headwater basins, the NWSRFS. The system consists of three conceptual models: (1) spatially lumped rainfall-runoff model, (2) spatially lumped soil moisture accounting model, which is a modified version of the Sacramento model, and (3) channel routing model in the form of a cascade of nonlinear reservoirs.

In routine operations, stream flow forecast is computed once a day for up to 10 days into the future. For instance, the Ohio River Forecast Center disseminates forecasts for about 110 river gauges. The forecast for a gauge specifies estimates of stages at 7 AM in 24, 48, and 72 hours, and estimates of flood crest and time to crest, if a flood event is probable. During floods, updated forecasts are produced more frequently.

The NWSRFS has received two enhancements. Georgakakos and Smith (1990) implemented an extended Kalman filter that updates the system based upon discharges at the basin outlet observed up to the forecast time. The implementation assumes that the dominant sources of forecast uncertainty are errors in estimates of model parameters and errors in observations of model inputs. Under these constructive assumptions, the deficiency of earlier hydrologic Kalman filters which lacked a procedure for estimating the time-varying covariance matrix of errors have been overcome. The second advance was reported by Sorooshian et al. (1993), who developed a global optimization procedure well suited to estimate parameters of conceptual hydrologic models, known to have response surfaces (relations between output errors and parameter values) dotted with numerous local optima. This strategy, dubbed the shuffled complex evolution method, was subjected to a test in which values of 13 parameters of the Sacramento soil moisture accounting model were optimized. Although the tests were limited, the new method consistently outperformed the well-known multistart simplex method, raising hopes that the day may be approaching when a hydrologist will be able to entrust the tedious task of parameter estimation to an automatic algorithm.

Rango and Martinec (1994) reported on a comparative test of seven hydrologic models conducted by the World Meteorological Organization. The test, which included flood events, provided an assessment of potential accuracy of daily snowmelt runoff forecasts for lead times of up to 20 days. Barrett (1993) described an application of NOAA's knowledge and technology to the development of a hydro-meteorological forecast system for the Nile River in Egypt. The system will provide daily forecasts of inflow to the High Aswan Dam and hydrographs at selected gauges upstream.

Quantitative Precipitation Forecasts

Flood forecast based solely on rainfall observed up to the forecast time carries with it an implicit prediction of no more rain, and such a prediction is the worst possible in the course of a severe storm. Yet a wider acceptance of the Quantitative Precipitation Forecast (QPF) as an input into a hydrologic model has been slow. Vis-a-vis the history of developments, recounted by Zevin (1994), the progress in the last four decades appears phenomenal. A number of NWS offices now routinely prepare QPFs for the purpose of river forecasting. New methodologies for producing QPFs are being developed. Techniques for preparing QPFs are being taught to hydro-meteorological forecasters as part of the NWS modernization program (Stewart et al., 1993). Case studies of recent flooding have documented the enormous utility of QPF-based river forecasts for flood warning decisions (Hughes, 1993), reservoir control (Eiben and Philips, 1993), and commercial navigation (Eiben and Yess, 1993). This review concentrates on methodological aspects of producing QPFs operationally for the purpose of forecasting floods on mainstream rivers.

a. QPF for river basins

For hydrologic purposes, QPFs are prepared by local NWS offices based on guidance products from NMC and TDL and other information. Forecasts are made routinely once a day and more frequently during flood situations. In general, there are two approaches.

In the service area of the Northwest River Forecast Center in Portland, Oregon, which has been using QPFs since the 1970s, the forecast is for a station and three days. It specifies estimates of precipitation amounts for eight 6-hourly sub-periods, during days one and two, and one 24-hourly sub-period, day three. Forecasts for 10 stations are then processed in the same manner as actual rain gauge observations to obtain forecasts of basin average precipitation amounts that are input to a stream flow model. Because of the strong orographic effects of the Cascade Mountains, temperatures are forecast as well to predict freezing levels that separate rainfall from snowfall and to estimate snowmelt runoff (Hughes, 1993).

In the service area of the Ohio River Forecast Center in Wilmington, Ohio, which has been using QPFs since the late 1980s, the forecast is for an area and one day. It provides graphical estimates of isohyets of the precipitation fields for four 6-hourly sub-periods. By integrating the fields over basins, estimates of basin average precipitation amounts are obtained. Temperature forecasts are used to classify the precipitation as rain or snow (Eiben and Yess, 1993).

b. Probabilistic QPF for river basins

The probabilistic approach (Murphy, 1991) is developed to forecast precipitation, which is the major source of uncertainty in flood forecasts. And because precipitation amount is one of the most difficult meteorological predictands, the uncertainty associated with any single estimate is high and varies from occasion to occasion. To allow the forecaster to convey the degree of uncertainty, to aid the predictor in coupling principles of weather forecasting with principles of probabilistic reasoning which leads to the quantification of uncertainty, to formulate a scheme for judgmental processing of information from multiple sources, and to automate all algorithmic processing tasks are the objectives of a new methodology (Krzysztofowicz et al., 1993).

5.2.4 Flood Warning Systems

Areas affected by flooding are typically large. Many different types of flooding occur, each with different requirements for satellite imagery. Two general categories are: river floods, which can be seasonal and are related to big rivers, or flash floods in smaller catchments; and second, coastal floods, frequently related to tropical cyclones or to high tides. Many factors play a role in the occurrence of flooding, such as the intensity and duration of rainfall, snow melt, deforestation, poor farming techniques, sedimentation in riverbeds, and natural or man-made obstructions. In the evaluation of flood hazards, the following parameters should be taken into account: depth of water during a flood, duration of the flood, the flow velocity, the rate of rise and decline, and the frequency of occurrence. In prevention exercises, SPOT stereo-pair images and ERS radar images can be used to generate digital terrain models for the simulation of potentially disastrous conditions and the identification of vulnerable areas. During and after the event, mapping of sequential inundation phases is possible, including the duration, depth of inundation, affected areas and direction of current. This can be done with automated classification from optical and radar satellite imagery. However, the most crucial data are derived from the calculation of the peak discharges and return periods, using supplemental data from gauging stations. It has been demonstrated that using satellite data for flood mapping becomes economically advantageous with respect to ground survey for areas larger than a couple of sq. km. However, a disadvantage in this domain is the long revisiting time of current high resolution satellites, which sometimes cannot allow the spacecraft to observe an event occurring between two successive passes.

For the prediction of floods, promising results have recently been reported on the use of NOAA images combined with meteorological satellites and radar data in the calculation of rainfall over large areas. For the monitoring of floods in large catchments, such as in Bangladesh, NOAA images have been successfully applied.

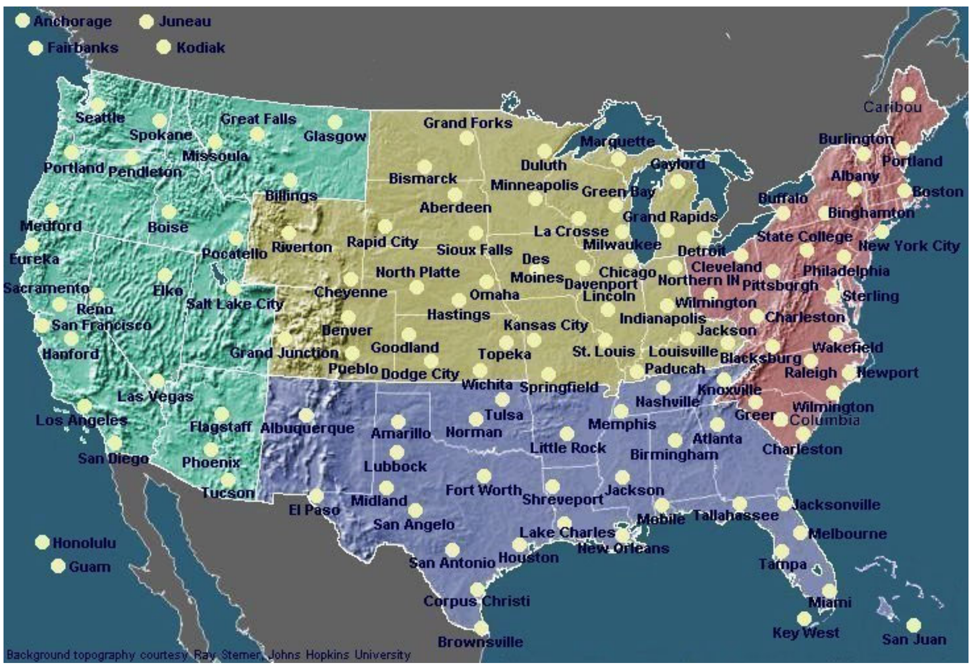


Fig. 5.2-2 (a) National Weather Service Offices and Forecast Centers (Source: NOAA, 2001)

5.2.5 NOAA

NWS offices and Forecast Centers in the U.S. are located at numerous places shown in Fig. 5.2-2 (a and b). NOAA and NWS provide the following information:

- Information on flooding (when necessary) and routine hydrologic conditions issued by NWS Forecast Offices
- Information about river stages and forecasts at locations along rivers
- Information on drought conditions throughout the country
- Information on soil moisture: indexes, observations and model estimates and forecasts
- In situ and remotely sensed observations of snow

- Information on water supply conditions, focusing on inflow forecasts for reservoirs
- Outlooks that provide insight into future hydrologic conditions, in particular precipitation

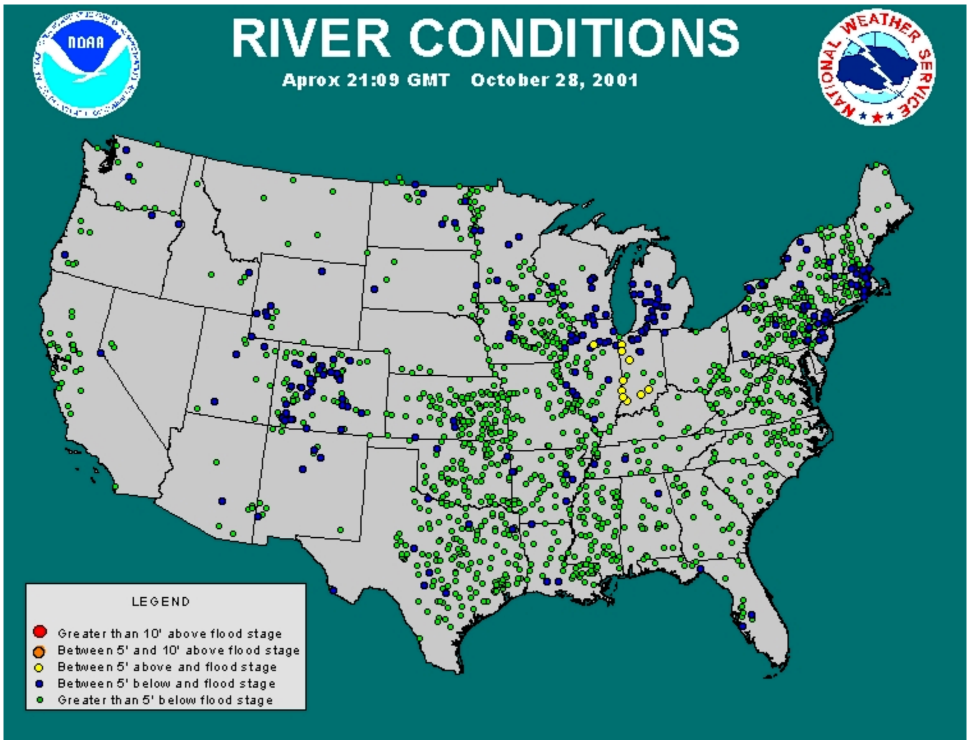


Fig. 5.2-2(b) National Weather Service Offices and Forecast Centers (Source: NOAA, 2001)

In the U.S., Doppler Radar Systems are located at numerous places, providing information about thunderstorms and rainfall. Such data are used to predict flash floods. Using Doppler radar data, radar mosaic is created twice per hour, from observations taken at WSR-88D sites around 00:15 and 00:45. The mosaic is composed of the highest observed reflectivity category within map grid boxes approximately 10 km (~5 nautical miles) on a side. It is designed to give an overall picture of the position, movement, and evolution of precipitation on a synoptic scale. The National Weather Service also distributes this mosaic in digital **GRI**dded **B**inary (GRIB) format under WMO message header HAXA00 KWBC. The reflectivity categories indicate the density of precipitation backscatterers (raindrops, snowflakes, hailstones, or ice pellets) within the lowest 10,000 feet of the atmosphere. Reflectivity and approximate surface rainfall rates for each category are shown in Fig. 5.2-3.

Level	dBZ	Rain Rate (in/hr)
0	<15	0 or Trace
1	**15-29**	**0.01 to 0.09**
2	30-39	0.1 to 0.4
3	**40-44**	**0.5 to 0.9**
4	45-49	1.0 to 1.9
5	**50-54**	**2.0 to 3.9**
6	**55>**	**>4**

Fig. 5.2-3 Reflectivity and approximate surface rainfall rates for each category (Source: NOAA, 2001)

The rain rates are approximations that hold only as long-term averages. Also, there is presently no reliable way to interpret reflectivity in terms of snowfall rate in cold-weather conditions. However, in any region in any given situation, higher reflectivity generally indicates a higher rate of precipitation at the surface. Gray areas on the graphic are those that are more than 230 km (approximately 120 nautical miles) from the nearest reporting radar, or which are shadowed by terrain features from any reporting radar. Though the WSR-88D detects reflectivity at much higher spatial and temporal resolution and with greater precision than that appearing in the Radar Coded Message, the reduced data format was chosen due to communications limitations present during the early part of the radar network's life cycle, in the late 1980s and early 1990s.

Creation of the mosaic

Individual radars transmit Radar Coded Messages (RCMs) twice per hour. The RCMs contain a coded text summary of reflectivity features in the local area, along with information on convective storms and the vertical wind profile near the radar. The reflectivity data have already been navigated to a fixed national map grid. The individual RCMs are integrated into one map grid at NWS headquarters. For grid boxes in which reflectivity is detected by more than one radar, the highest reported value is put into the final product and it is used for the forecast of weather condition and prediction of rainfall (Fig. 5.2-4).

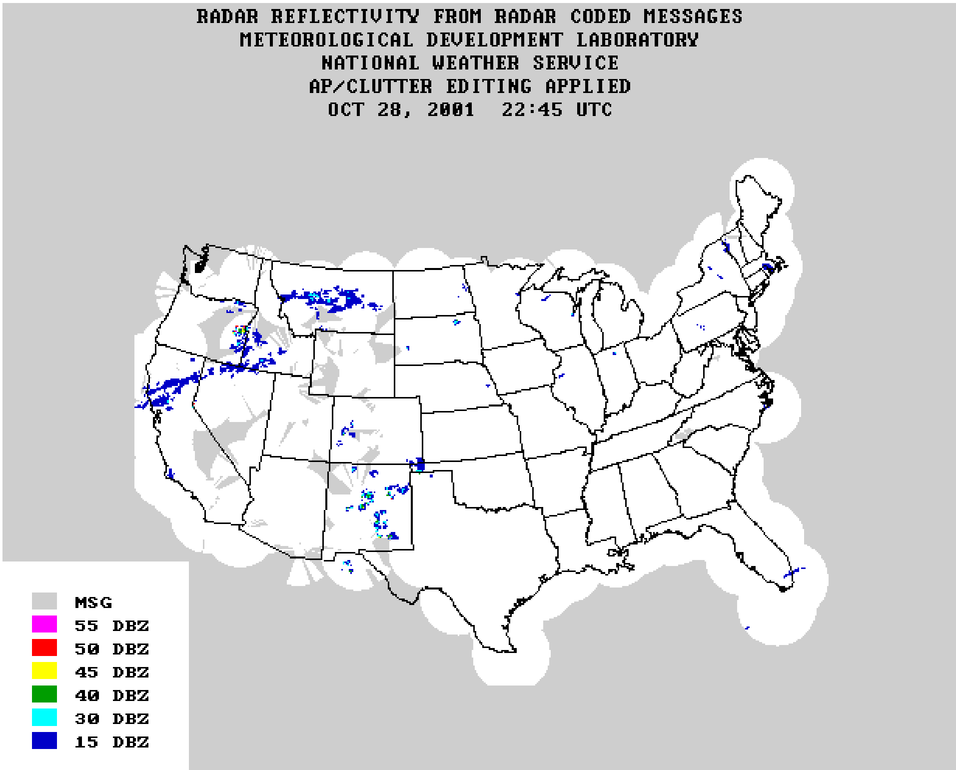


Fig. 5.2-4 Radar reflectivity from radar coded messages meteorological development laboratory national weather service (Source: NOAA)

5.3 Flood Warning Services of Bureau of Meteorology (Australia)

The flooding of rivers following heavy rainfall is the most common form of flooding in Australia. Very high tides are another cause of flooding in coastal areas. Flooding of rivers in inland areas of central and western New South Wales and Queensland, as well as parts of Western Australia, can spread for thousands of square kilometers and may last for weeks or even months. In hilly or mountainous areas of these inland rivers, as well as in rivers draining to the coast, flooding can occur more quickly. These rivers are steeper, and flooding often lasts for only one to two days. Flash flooding usually results from relatively short intense bursts of rainfall, commonly from thunderstorms. This flooding can occur in most parts of Australia, but is a particularly serious problem in urban areas where drainage systems may not be able to cope, and in very small creeks and streams. Flash floods tend to be quite local and it is difficult to provide effective warning because of their rapid onset.

The primary function of the Flood Warning Service Program is the provision of an effective flood forecasting and warning service in each Australian State/Territory. This service is provided in cooperation with other government agencies such as State/Territory emergency management agencies, water authorities and local councils, coordinated through Flood Warning Consultative Committees and established cooperative working arrangements in each State/Territory. Efforts are made in Australia for national flood warnings and to provide river information on the basis of rainfall (Fig. 5.3-1). The Bureau of Meteorology provides a flood warning service for most major rivers in Australia. This service is provided with the cooperation of other government authorities, such as the State Emergency Service (S/TES) in each State/Territory, water agencies and local councils. The Bureau delivers this service through Flood Warning Centers and Regional Forecasting Centers in Bureau Regional Offices in each State and the Northern Territory.

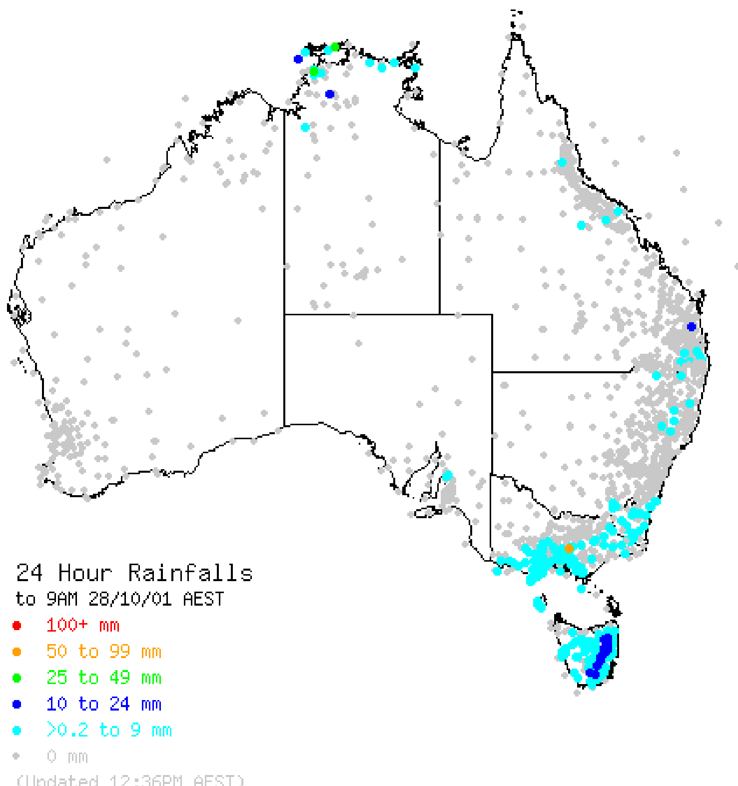


Fig. 5.3-1 Twenty-four hour rainfalls in Australia (Source: FWSBM, 2001)

The Flood Warning Service provides different types of information that depends on the type of flooding and the flood risk. The range of information, which may vary between states and areas within a state, includes:

An Alert, Watch or Advice of possible flooding, if flood-producing rain is expected to happen in the near future. The general weather forecasts can also refer to flood producing rain.

A Generalized Flood Warning that flooding is occurring or is expected to occur in a particular region. No information on the severity of flooding or the particular location of the flooding is provided. These types of warnings are issued for areas where no specialized warnings systems have been installed. As part of its Severe Weather Warning Service, the Bureau also provides warnings for severe storm situations that may cause flash flooding. In some areas, the Bureau is working with local councils to install systems to provide improved warnings for flash flood situations.

Warnings of 'Minor', 'Moderate' or 'major' flood in areas where the Bureau has installed specialized warning systems. In these areas, the flood-warning message will identify the river valley, the locations expected to be flooded, the likely severity of the flooding and when it is likely to occur.

Predictions of the expected height of a river at a town or other important locations along a river, and the time this height is expected to be reached. This type of warning is normally the most useful in that it allows local emergency authorities and people in the flood threatened area to more precisely determine the area and likely depth of the flooding. This type of warning can only be provided where there are specialized flood warning systems and where flood-forecasting models have been developed.

In order to get the most benefit from flood warnings, people in flood prone areas will need to know what, if any, effect the flood will have on their property and some knowledge of how best to deal with a flood situation. Sources of such information could include:

- Flood Bulletins/Warnings issued by the Bureau and/or the local council or emergency services which often contain details of areas affected by flooding, road closures and other advice on what the community should do if they are likely to be flooded
- Long term residents who may have experienced a similar flood in the past and remember how it affected them
- Local councils which have conducted flood studies and have maps of areas that are likely to be flooded by a range of floods
- Information pamphlets - see Further Information section below.

Flood warnings typically include a statement about both current and expected levels of flooding at key locations in the area covered by the warning, along with a weather forecast and the latest available observations of river height and rainfalls in the area. In the interpretation of warning messages, it is important to note that the predicted height is a river level above a certain datum, and not a depth of floodwater. The Bureau role is to provide flood warnings, some of which contain forecasts of expected river heights. Other agencies (local councils, S/TES, etc.) are responsible for interpreting river levels into depths and areas of inundation. People living in flood prone areas should consult with these agencies to find out what level of warning service is operated for their area. In each state, flood warnings and river height bulletins are available via some or all of the following:

Local Response Organizations: These include the council, police, and State Emergency Service in the local area.

Bureau of Meteorology: Flood warnings and general information are available directly from the Bureau in each state.

Radio: Radio stations, particularly local ABC and local commercial stations broadcast warnings (and bulletins) soon after issue.

Telephone Recorded Information Services: Flood warnings are available in some states on a Bureau of Meteorology recorded message service. Charges apply.

Internet/World Wide Web Access: The Bureau home page is http://www.bom.gov.au/

Weather by Fax: Flood warnings and river height bulletins are available through INFORMATEL, a facsimile information retrieval system, along with a wide range of other weather and climate information. Charges apply.

Probable Maximum Precipitation (PMP) Estimates can be produced for any catchments in Australia. There are 3 Generalized Methods used to estimate PMP, appropriate for different locations and durations:

- Generalized Short-Duration Method (GSDM);
- Generalized Tropical Storm Method (GTSM); and
- Generalized Southeast Australia Method (GSAM).

Probable Maximum Precipitation (PMP) is defined by the Manual for Estimation of Probable Maximum Precipitation (WMO, 1986) as the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends. A PMP report provides the PMP depth, averaged over the catchments, as a function of duration, from 1 hour to a maximum of 4 days depending on the location; the spatial distribution of the rainfall over the catchments; and the temporal distribution of the rainfall during the period of the PMP storm. Hydrologists use a PMP magnitude, plus its spatial and temporal distributions, to calculate the Probable Maximum Flood (PMF) for the catchments of a dam. The PMF is used to design the dam.

Generalized Methods of estimating PMP use data from all available storms over a large region and include adjustments for moisture availability and differing topographic effects on rainfall depth. Smoothing over a range of areas and durations envelops the adjusted storm data. Generalized methods also provide design spatial and temporal patterns of PMP for the catchments.

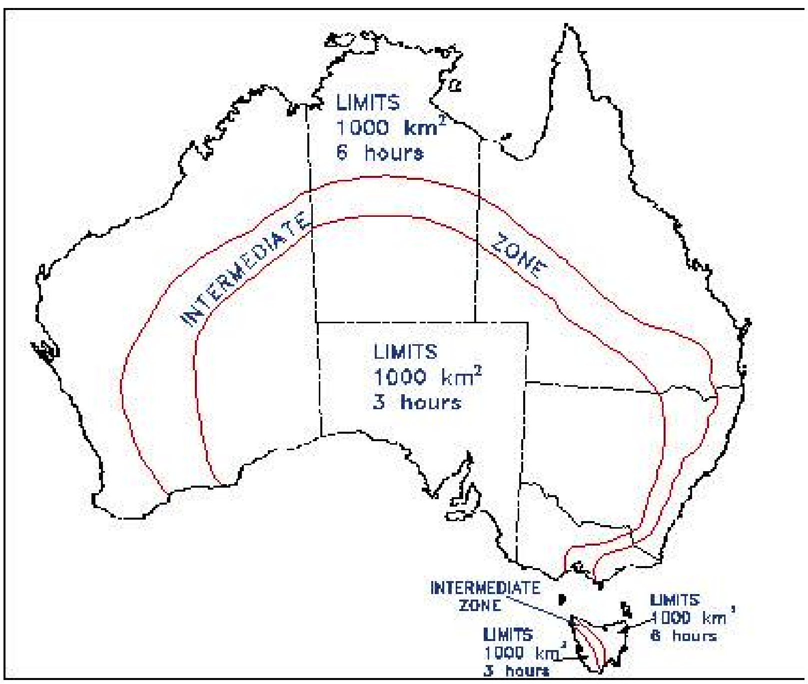


Fig. 5.3-2 Generalized Short-Duration Method of estimating PMP (Source: FWSBM, 2001)

a. The Generalized Short-Duration Method is appropriate for durations up to 6 hours, suitable for small catchments such as those of reservoirs and tailings dams anywhere in Australia. GSDM PMP estimates may be obtained by following the procedures in Bulletin (Fig. 5.3-2,3).

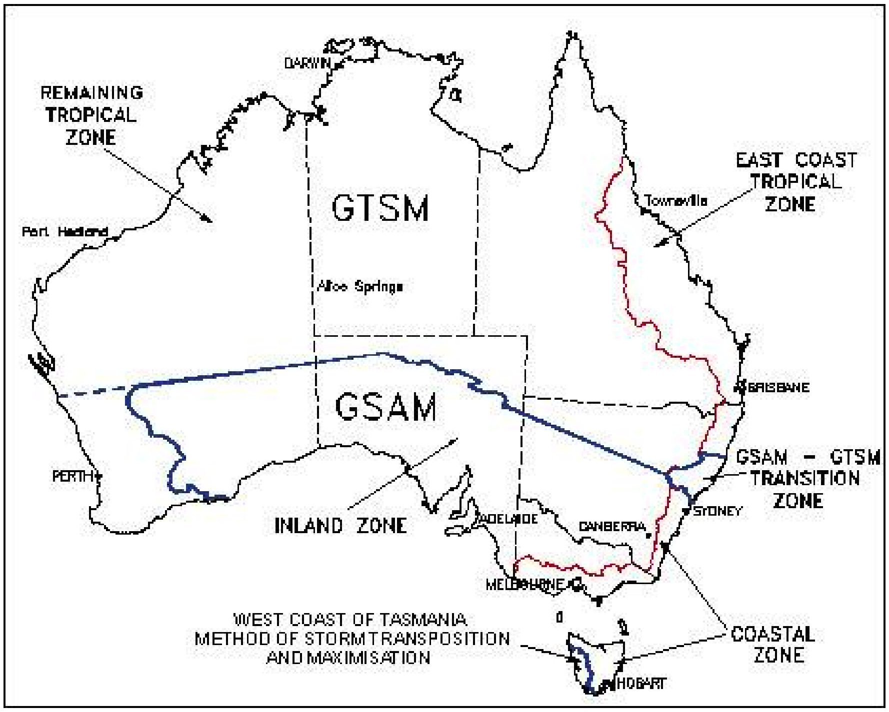


Fig. 5.3-3 Generalized Tropical Storm Method for estimating PMP (Source: FWSBM, 2001)

b. The Generalized Tropical Storm Method (GTSM) is applicable to those parts of Australia affected by tropical storms. The method was developed during the mid-1970s and finalized in 1985. The final boundary for application of the method was determined in 1987. The area to which the method can be applied is divided into two regions: the East Coast Tropical Zone (ECTZ), where a persistent low pressure trough can enhance and prolong rainfall from tropical cyclones and other tropical low pressure systems, and the Remaining Tropical Zone (RTZ). The GSTM is appropriate for durations of 6 to 72 hours (96 hours in the ECTZ).

The Generalized Southeast Australia Method (GSAM) was developed for estimating PMP in those regions of Australia where tropical storms are not the source of the greatest depths of rainfall, and where topographic influences vary markedly. Development commenced in 1985 and was completed in 1992. Daily rainfall analysis is made for each station.

5.4 Atmospheric and Hydrological Model for Flood Forecasting (Canadian model)

Combining weather forecasts with information on watershed conditions and a hydrological stream flow forecasting model can give advanced warning of potential flooding. Coupling to a well-calibrated high-resolution model not only offers a valid substitute for precipitation data, but more importantly it provides a means to compute forecast river flows. The optimal coupling of a high-resolution regional atmospheric model with a hydrological model (WATFLOOD) for flood forecasting has been developed by the Canadian scientists. A conceptual framework for model development was initiated using different degrees of model coupling to obtain a complete two-way coupled model. The first level of coupling is referred to as model linking and requires calibration and validation of the high-resolution regional atmospheric model and the distributed hydrological model separately. This form of coupling was used to simulate precipitation from the atmospheric model to drive the hydrological model to study flash flood events. Under this modeling scenario, the two models use their own inherent land surface scheme and parameterizations. The hydrologic model forcing is derived directly from the atmospheric forecasts with the dominant input being precipitation. This is of great interest as precipitation is the single most uncertain variable for such hydrological studies.

For the next two coupling levels, implementing a common land surface scheme in each model and re-calibrating the models separately first establish the link between the models. This phase of the model development includes level-I coupling (atmospheric and land surface) and level-II coupling (land surface and hydrologic). The final stage of coupling is the complete two-way coupled system using the common land-surface scheme and the parameter identification established during the level-I and II coupling. The detail of the forecast model (WATFLOOD) developed by the Canadian scientists is discussed in the forthcoming section.

5.4.1 WATFLOOD

WATFLOOD is a physically based simulation model of the hydrologic budget of a watershed that represents only a small part of the overall physical processes occurring in nature. The model is aimed at flood forecasting and long-term hydrologic simulation using distributed precipitation data from radar or numerical weather models. The processes modeled include interception, infiltration, evaporation, snow accumulation and ablation, interflow, recharge, base flow, and overland and channel routing (Kouwen et al., 1993).

The model is programmed in FORTRAN 95 with dynamic memory allocation to make it suitable for use on any modern computing platform. Typically, the program takes approximately 1 minute to run for a 50,000 km^2 watershed with a 10 km grid, 1-year simulation, and hourly time steps on a 800 Mhz Pentium III™.

The following sections describe the model and the input requirements. In addition to SPL9, there are a number of support programs to provide for data preparation and output presentation. The programs RADMET and RAGMET may be used to convert radar and rain gauge data to the square grid SPL9 input format; BSN may be used to assemble and create a 'basin file' for SPL9; and PLOTHYD is a program to plot hydrographs on a color monitor. The WATFLOOD menu program can be used to manage the data and organize the use of the model.

The model features the Hooke and Jeeves (1961) automatic pattern search optimization algorithm taken from Monro (1971). The program can be run to automatically determine which combination of parameters best fit measured conditions. The parameters for optimization are soil permeability, overland flow roughness, channel roughness, depression storage, and an upper zone depletion factor.

<u>Approach</u>

A simple example is shown to demonstrate why weighted averages for the parameters that define the runoff characteristics of a watershed should not be considered. Visualize a one-hectare city block and divide it into two parts, with two-thirds of the area grassed and the remaining one-third impervious. If the U.S. Soil Conservation Service method is used to determine runoff, and the soil curve number for the grass is taken as 50, the weighted SCS number will be 67 and runoff will not commence until approximately 25 mm of rain have fallen (USDA, 1968). However, the impervious area will contribute runoff almost as soon as the precipitation starts. Using the same scenario, if the rational method is applied to the same area, a peak flow calculated using only the impervious area will be larger than using the whole area.

These inconsistencies have been known for a long time and led to the development of hydrological models, which did not require the averaging of the watershed parameters. The first of these, where runoff was computed separately, was using the Road Research Laboratory Method (Terstriep and Stall, 1996) followed by many others. The general trend has been to model areas of uniform hydrologic response such as the method developed by Leavesly and Stannard (1995) based on the Hydrologic Response Unit (HRU) method. During the last 15 to 20 years, "pixel models" have been developed where the hydrology is modeled at the scale of the pixel of LANDSAT or SPOT imagery or the resolution of the digital terrain data as for the TOPMODEL (Beven et al., 1995) or the MIKE SHE model (Refsgaard and Storm, 1995). However, the problem is where to make the cutoff for the smallest area that can be modeled. Often the determining factors are the image resolution and/or the computer resources available. This appears to be a rather arbitrary criterion, not based on hydrological considerations.

The WATFLOOD method is based first on a definition of the resolution of the meteorological data available and second, on the level of detail required in the output, for instance, the size of the smallest watershed for which information is sought. Once these general parameters are established, a model grid is chosen to reflect these points. On very large watersheds on the sub-continental scale, where a numerical weather model with a resolution of 25 km may provide the meteorological data, a 25 km grid size will be appropriate. On the other hand, for a small 100 km^2 watershed, where the precipitation may be provided by radar at a 1 km resolution, a 1 km grid would be more appropriate.

Any land cover image will reveal differences between neighboring pixels. Unless a model grid size is chosen that is equal to the land cover pixel size, either the hydrologic parameters will have to be averaged or different hydrological units will have to be grouped. The WATFLOOD system is based on the latter. Using remotely sensed land cover data, pixels are classified to a number of land cover classes and the ratio of each land cover in each computation grid is determined. The runoff response from each hydrologically significant sub-group in each grid is calculated and routed downstream. With this method, there is no requirement for grids or sub-basins to be hydrologically homogeneous. So, the grid size can be chosen to conveniently match the resolution of the meteorological data or reflect the detail required in the model output.

Fig. 5.4-1 shows the above concept. In this example, a land cover image is classified into 4 hydrologically significant groups A, B, C and D. There are 25 pixels with 8 in group A, 11 in group B, 2 in group C, and the remaining 4 in group D (i.e., 32% in group A, 44% in group B, 8% in group C and 16% in group D). WATFLOOD combines all pixels in one group for computational purposes. The pixels of one group do not have to be contiguous and their location in the grid is not considered significant with respect to routing. The runoff from a grouped set of pixels is routed by a two steps procedure, first overland flow to the channel system and second, channel flow to the next grid.

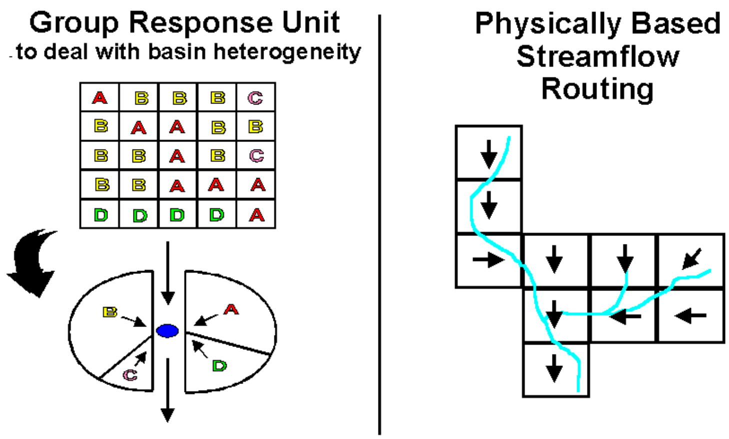


Fig. 5.4-1 Group response unit and runoff routing concept (Donald, 1992)

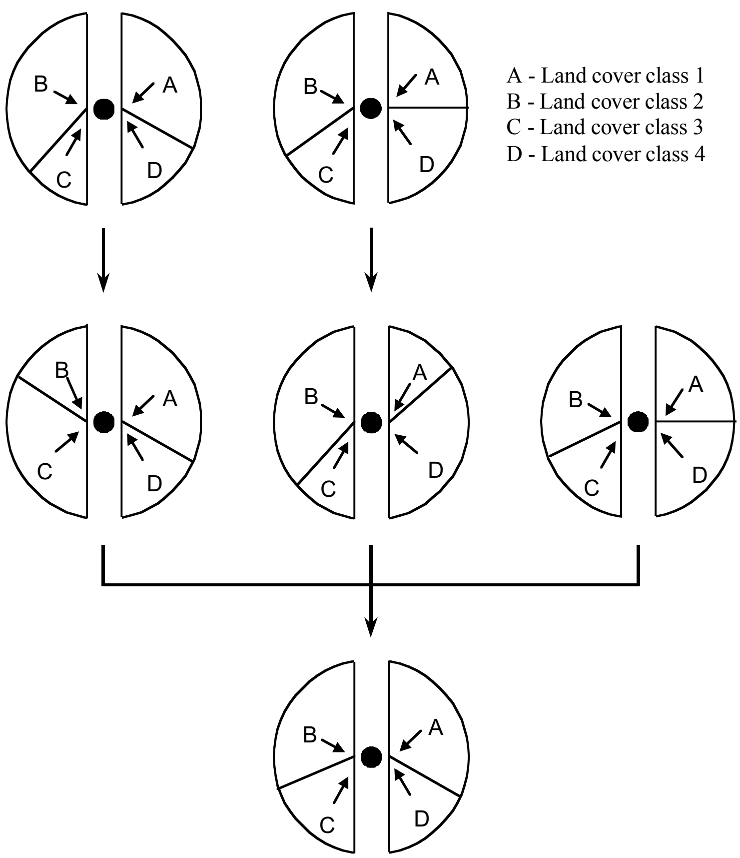


Fig. 5.4-2 Schematic of the GRU pixel grouping model and channel routing scheme

For the grid in Fig. 5.4-1, there are four hourly runoff computations and four overland flow routing segments. The flows are then combined for the grid. If there are four sub-watersheds in this grid in a pie-shaped configuration, each segment contributes runoff according to its percent coverage. The four-runoff amounts are added in each grid and routed downstream from grid to grid.

Fig. 5.4-2 shows an array of grids where each grid may have a different makeup of land cover fractions. The essential property of this arrangement is that the parameters are associated with the land cover classes A, B, C and D. All grids in this method have the same hydrological parameters, even though the land cover makeup of each grid is not the same. The advantages of this scheme are: 1) the parameters can be used in other physiographically similar watersheds without recalibration, and 2) the parameters do not have to be recalibrated if land use in the watershed changes over time. For the latter, only the land cover map and the fractions in each grid need to be redefined.

5.4.2 Quantitative Precipitation Estimation for Streamflow Modeling in Ontario, Canada

Recently, efforts have been made to use various hydrological parameters derived from remote sensing data for hydrological practice. Use of observed precipitation through Doppler radar and their use in hydrological modeling are presently underway. The use of such tools may lead to improved accuracy in the estimation and short term forecasting of stream flow conditions. Such potential improvements could also lead to an expansion of the capacity of information systems in hydrology and could have implications in the future design of ground-based hydrological networks. Within this effort, precipitation fields are estimated using a portion of Environment Canada's Doppler weather radar network.

Environment Canada is midway through a project to upgrade its network of C-band Doppler weather radars. Fifteen radars have been installed or upgraded and by 2004, a complete network of thirty radars will provide coverage for approximately ninety-five percent of the population of Canada. The main focus of these systems is to improve the forecasting of severe weather. Suites of radar products are being developed and various efforts are underway to increase their utility in estimating rainfall intensity and its areal distribution. Use of C-band radar poses unique problems that require novel approaches to obtain accurate precipitation fields. Evolving capabilities and approaches represented within the Unified Radar Processing System are used with a distributed hydrological model to evaluate performance.

Estimated flow values from a distributed hydrological model, WATFLOOD, set up over selected pilot basins, are compared to estimated flows from hydrometric gauges representing drainage areas ranging from 100 to 3500 km^2. WATFLOOD is a grid-based model developed by the University of Waterloo, Ontario. The model characterizes watersheds by using high resolution LANDSAT images to identify various hydrologically similar land types which are subsequently grouped within each hydrological model grid cell to create grouped response units (GRUs).

In one watershed equidistant two C-band Doppler radars are kept for measuring precipitation. In the pilot study, 100-day periods during summer several intense rainfall events are measured. The measurements provide an opportunity to quantify the effects of radar beam attenuation and other artifacts on estimating precipitation fields through the use of a distributed hydrological model.

Hydrological model output from both conventional and Doppler radar products are compared against gauged flows on unregulated headwater basins to provide a means of examining quantitative precipitation estimates on an areal basis that complements point observations. Several assumptions and alternatives regarding the generation of gridded QPE fields using radar and integrated data sets are investigated. A comparison of hydrological model performance to observed flow is shown for various radar/precipitation interpolation techniques. These experiments help to explore and quantify model sensitivity and performance under various hydrological grid cell resolutions and radar products.

5.5 Wide Area Flood Risk Monitoring Model

Arten et al. (2001) developed a Stream Flow Model for wide area flood risk monitoring tool. It is used to monitor stream locations with extreme flows caused by prolonged regional rainfall pattern. The model concept involves parameters such as: Evaporation, Transpiration, Precipitation, Surface runoff, Interflow, Flow, Percolation and Loss to ground water. These parameters involve input for flow direction, flow accumulation, flow length, terrain slope, hill length, soil and land cover characteristics, and rainfall estimates. All the parameters are important as input for the flood forecast. Among all the parameters, the rainfall estimation at various locations along the river and its tributaries is important.

5.6 MIKE-11 Flood Forecast System (Danish)

MIKE-11, developed by the Danish Hydrologic Institute, is a professional engineering module based on a real-time flood forecasting system for the simulation of flows, water quality, and sediment transport in rivers, channels, irrigation systems, and other water bodies. As a dynamic, menu-driven modeling tool for the detailed design, management, and operations of simple and complex river and channel systems, MIKE-11 output products include:

- Real-time management system with direct access databases and user-designed data entry menus
- Calculations of mean real rainfall from point rainfall in sub-catchments
- Calculations of discharge from water level data and rating curves
- Hydrodynamic modules for routing river slows and predicting water levels and inflows to reservoirs
- Automatic updating procedures for minimizing differences between observed and simulated flow/water levels at time of forecast
- Specification of quantitative precipitation forecasts and predictions of boundary inflow in the forecast period

5.7 European Flood Forecasting System

The European Flood Forecasting System (EFFS) project contributes to the Energy, Environment and Sustainable Development Programme for Research, Technology development and Demonstration (RTD) under the fifth Framework Programme of the European Commission. More precisely, it forms a contribution to Research and Technology Development Activities of a Generic Nature, Fight against Major Natural Hazards with RTD priority Floods and Hydrogeological risks.

The EFFS project aims at developing a prototype of a European flood forecasting system 4-10 days in advance. This system provides daily information on potential floods for large rivers such as the rivers Rhine and Oder as well as flash floods in small basins. This flood forecasting system can be used as a pre-warning system to water authorities that already have a 0-3 day forecasting system. The system can also provide flood warnings for catchments that at present do not have a forecasting system (Eastern-European countries). The framework of the system will allow incorporation of both detailed models for specific basins as well as a broad scale model for entire Europe. Once designed, the prototype will be tested and evaluated for several months. Together with end-users, channels to disseminate the forecasts and their uncertainties will be developed. The main objectives of the project are:

- To take advantage of currently available Medium-Range Weather Forecasts (4 - 10 days) to produce reliable flood warnings beyond the current flood-warning period of approximately 3 days.
- To design a Medium-Range Flood Forecasting System for Europe that will produce flood warnings on the basis of the Medium Range Weather Forecasts.
- To produce flood forecasts in regions where at present no flood forecasts are made on the basis of the newly developed system.

5.7.1 Prediction and Mitigation of Flash Floods

Although structural measures of protection (e.g., flood control reservoirs) can provide some protection from flooding from larger streams with longer flood lead times, it is too costly to use flood control structures on the large number of small streams flowing through populated areas. Moreover, it is difficult and costly to construct and then continuously monitor the safety of all structures that could mitigate flash flood disasters. Therefore, it is vitally important to reduce the population living in floodplains by providing disincentives to encroachment. This is one of the goals of the national flood insurance program of the Federal Emergency Management Agency (FEMA) of the U.S.

Nevertheless, since too many people still dwell along small streams that can easily flood, community warning systems and self-help programs provide the only practical safeguard for many small flood plain communities.

5.7.2 Warning systems and new technologies

<u>Essential components of flash flood warning systems include the following:</u>

- Preparedness programs that include local citizen involvement.
- Rainfall-observing systems.
- Electronic data communication systems.
- Diagnostic/predictive models.
- Model calibration procedures.
- Warning dissemination systems.

- Action plans for local civil authorities.

In fact, many of the accomplishments in forecasting and improved warnings for flash flooding have come from the application and utilization of a number of these program components. For example, the NWS lead time for flash flood forecasts has increased to over 50 minutes. Much of this improvement is directly tied to new technology and also training along with the introduction of hydrometeorologists in the Weather Forecast Offices. Deployment of new weather surveillance radars nationwide has significantly improved the capability to continuously monitor intense localized rainfall.

Furthermore, upgrading the new radar network to include polarimetric capabilities may offer substantial potential for significant additional improvements in rainfall measurements. The new radar technology, when combined with satellite and advanced automated surface rainfall and stream flow technologies, enhances the prospects for detecting and quantifying intense rainfall and rapid rises in stream flow. Still further, the databases created by the new observing capabilities facilitate better studies of the physical character of such rainfall events. This is especially true for understanding flash flood dynamics and microphysical processes, knowledge that is vital for the development of improved radar rainfall estimates. For example, improved understanding of radar underestimation of "warm-process" rain will ultimately lead to further improvements in diagnostic and forecast models. Because both remotely sensed and on-site recorded data are necessary for the production of high-resolution (to a few square kilometers) optimal estimates of rainfall, deployment and maintenance of rain gauge networks will still be important components of hydrologic research and development. A major challenge for remote sensing systems is enhancement of rainfall estimation capabilities in complex terrain.

5.7.3 Integrated hydro-meteorological approaches

The coupled meteorological–hydrological nature of flash floods is becoming more and more evident. Prediction of flooding events will require interactive meteorological and hydrological models that introduce new weather radar data and include feedbacks from the near-surface soil water to the atmosphere. Coupled hydrological–meteorological models should be constructed in a manner that permits prediction of time and space distribution of both rainfall and resultant flooding. Efforts to predict the temporal and spatial distribution of flooding are expected to dominate research and development of diagnostic/predictive models. Considerable efforts have been expended to develop probabilistic approaches to heavy rainfall and flood forecasting. Early efforts during the late 1990s have shown dramatic improvements in warnings when forecasters are trained and fully engaged in understanding the strengths and drawbacks of utilizing probabilities to express their confidence in their rainfall forecasts. Additional work also must be done to improve automated stream gauging systems and to improve integrated rainfall–stream flow prediction systems that integrate models with observations.

<u>Important research challenges include:</u>

- Understanding the processes that govern the production of extreme rainfall rates in convective weather systems

- Determining why some convective systems become quasi-stationary
- Defining the effects of the initial spatial distribution of soil moisture on the development of surface runoff
- Developing reliable distributed hydrologic models for simulating the hydrologic response of urban areas
- Linking local distributed hydrologic models to the larger-scale hydrologic models used operationally by the river forecast centers of the NWS
- Establishing the fundamentals of small-catchments hydrology/hydraulics
- Quantifying forecast uncertainty by providing probabilistic forecast guidance

The influence of the spatial scales of soil moisture on flash flood modeling is to support basic research efforts. Data requirements for conducting the research and developing predictive models necessitates utilization of geographic information systems for specifying catchments geometrical properties pertinent to surface runoff development. Because the occurrence of flash floods depends strongly upon the local nature and dynamics of rainfall and upon the wide spectrum of spatial and temporal scales that such dynamics span, fundamental uncertainties are inherent in any attempt to forecast these events. These uncertainties make it necessary to use statistical–dynamical predictive rainfall models. They also encourage exploration of probabilistic approaches, including ensemble-forecasting techniques.

Dissemination of flood warnings has improved in recent years, largely in response to the enhanced coverage and attention of the local commercial media. Public response to warning would improve if individual streams were identified in the warning messages. Also, enhanced NOAA Weather Radio coverage of flash flood-prone areas over the United States would undoubtedly contribute to smaller disaster impact. Dissemination methods involving the Internet should be explored and tested.

Proactive preparedness programs remain indispensable for loss-of-life and flood-damage reduction. Continued efforts by the NWS, FEMA, the media, and state and local emergency management agencies to educate the public regarding the occurrences and destructive force of flash floods are essential. Improved community monitoring, detection, and warning programs with emphasis on individual warning responses are a must. Real-time feedback from local designated persons or authorities to the NWS offices as to the hydrological and meteorological aspects of flood development will make a more effective warning system.

Present-day flash floods are severe calamities with the potential for a very high death toll and huge losses of property. Although forecasting such events remains a tremendous challenge, the availability of the new weather radar data is expected to enhance forecast reliability, at least for short forecast lead times. Nevertheless, integrated hydro-meteorological approaches based on sound science and new technological advances are necessary if more reliable and timely predictions are to become a reality. Coordinated dissemination and preparedness programs that involve individual and government initiatives will remain essential for effective flash-flood hazard mitigation.

5.8 Flood warning from space in Europe

River and civil protection authorities in Europe are using mathematical models of their river basins to identify the areas at risk and to assess flood defenses. Unfortunately, the models currently in use are not accurate enough. Measurements are difficult to take during a flood, and model calibration must rely on historical records and aerial photographs. Two European satellites with Synthetic Aperture Radar (SAR) instruments, now orbiting the earth, can provide an all-weather capability to monitor floods from space.

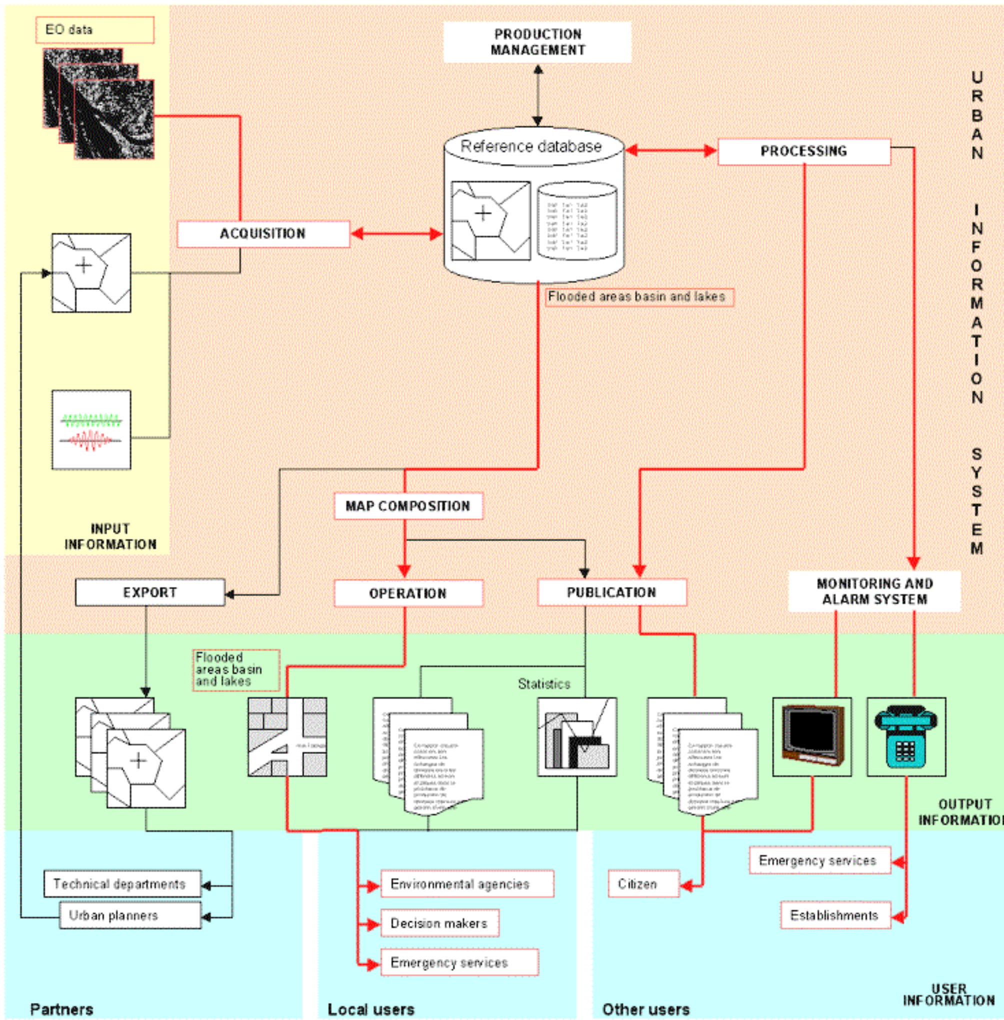


Fig. 5.8-1 Various Steps of LISFLOOD

The Water Management Model (WAMM) project uses a European modeling tool (MIKE11) of the flood plain to predict flood extent. By including SAR data in the model, the accuracy of flood prediction and the efficiency of flood prevention are significantly enhanced. Model calibration is made by comparing its predictions with actual flood maps obtained through the analysis of SAR satellite images and water levels measured by small portable sensors installed in the flood plain.

A model called LISFLOOD is under development for simulating floods in large European drainage basins. Full basin-scale simulations can be carried out, such that the influences of land use, spatial variations of soil properties and spatial precipitation differences are taken into account. LISFLOOD is a distributed rainfall-runoff model taking into account the influences of topography, precipitation amounts and intensities, antecedent soil moisture content, land use type and soil type. The processes simulated are precipitation, interception, snowmelt, evapotranspiration, infiltration, percolation, groundwater flow, lateral flow and surface runoff. For surface runoff and channel routing, a GIS-based kinematic wave routing module has been developed. The user can choose both spatial and temporal resolution. For flood prevention the important key approach is sustainable management of land cover and land use in the catchments area. Geodata on catchments level are also needed for extended and more reliable flood prediction through precipitation run-off modeling.

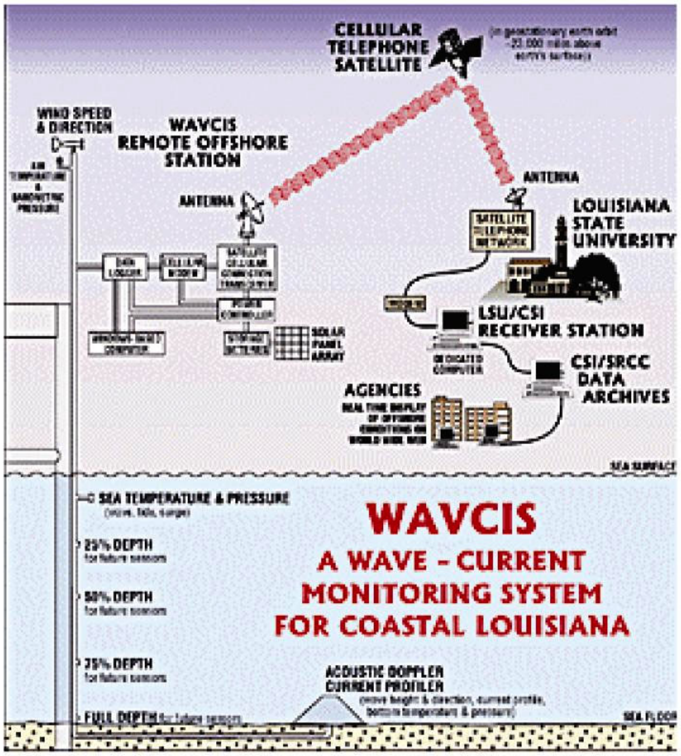
Rhine-GIS is useful for flood prediction models and early-warning-systems (Fig. 5.8-1), as it is innovative in many aspects:

- It covers the whole catchments area of the Rhine (about 186.000 km^2), with a resolution of 500 m pixel size.
- The concept is spatially oriented and comprises of 36 data layers, it covers all important, constant and "near-constant" physiographic features relevant for hydrological modeling.
- Satellite data and their derivatives are integrated to provide information on highly variable parameters such as vegetation.

Simulated flood hydrographs at user defined catchments outlets and sub-outlets produce hydrographs for historic floods and land use scenarios. Maps are produced showing the source areas of water in the catchments, which are used for spatial planning. Maps show the maximum flood extent in the floodplain during historic floods and as a consequence of a land use change (scenario). Maps show changes in space and time of certain variables, such as water depth. For the Rhine-GIS product, data are supplied on CD-ROM in formats open to every GIS software. It provides basic data to input into a range of models. It is important to stress that the use of Earth observation data within flood models is still at a development stage. Earth observation can produce information on vegetation, landcover and elevation, but the value of this information within models is under validation.

5.9 Wave Current Information System (WAVCIS)

Floods are often caused in the coastal areas due to ocean current. The objective of wave-current information system (WAVCIS) is to provide wave information (sea state) including wave height, period, direction of propagation, water level, surge, near surface current speed and direction and meteorological conditions on a real time basis around the entire Louisiana coast (Fig. 5.9-1).



The Wave-Current Information System is a state-of-the-art instrument array capable of providing real-time data on storm surge and other factors affecting vulnerable coastal communities during hurricanes and smaller disturbances in the Gulf of Mexico. Such predictions would provide a decided advantage to the disaster response community. *(Click to jump to larger image.)*

Fig. 5.9-1 A wave – current monitoring system for coastal Louisiana

5.10 DECIDE Belgium Flood project (Earth Observation Technologies for Decision Support Demonstrations - The Flood Case)

In Walloonia (south of Belgium), SETHY (Service d'Etudes Hydrologiques) belonging to the MET (Ministère wallon de l'Equipement et des Transports) is responsible for the maintenance and development of a system allowing the hydrological monitoring of the Walloon territory (16,844 sq. kilometers; 5 provinces: Hainaut, Brabant Wallon, Namur, Liège and Luxembourg). SETHY is the end-user of DECIDE project. For DECIDE demonstrator, the Lesse catchments was chosen. The Lesse River is a tributary of the Meuse and is located in the Belgian Ardennes. It was selected since it is a basin that has been studied for years and is therefore well known. Many tools and digital data already exist such as GIS data, remote sensing data, calibrated and validated models.

The EFFS project aims at developing a prototype of a European flood forecasting system for 4-10 days in advance. This system provides daily information on potential floods for large rivers such as the rivers Rhine and Oder as well as flash floods in small basins. This flood forecasting system can be used as a pre-warning system to water authorities that already have a 0-3 day forecasting system. The system can also provide flood warnings for catchments that at present do not have a forecasting system (Eastern-

European countries). The framework of the system will allow incorporation of both detailed models for specific basins as well as a broad scale model for entire Europe. Once designed, the prototype will be tested and evaluated for several months. Together with end-users, channels to disseminate the forecasts and their uncertainties will be developed.

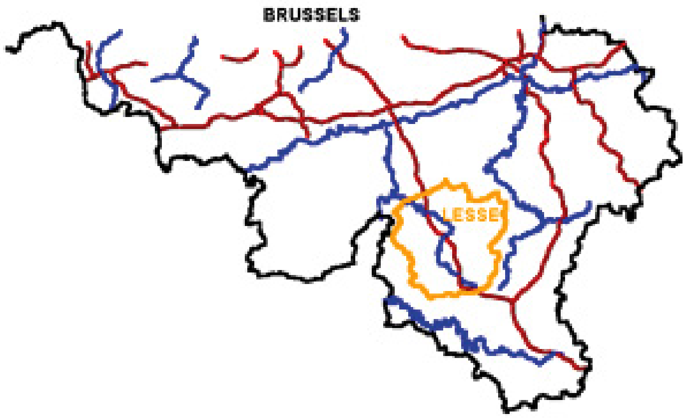


Fig. 5.10-1 Walloon territory and Lesse river

The main objectives of the project are:

- To take advantage of currently available Medium-Range Weather Forecasts (4-10 days) to produce reliable flood warnings beyond the current flood-warning period of approximately 3 days.
- To design a Medium Range Flood Forecasting System for Europe that will produce flood warnings on the basis of the Medium Range Weather Forecasts.
- To produce flood forecasts in regions where at present no flood forecasts are made on the basis of the newly developed system.

5.10.1 Scientific Objectives

The following scientific objectives were planned:

- Development and application of downscaling techniques for weather forecasts that can be used in real-time operational flood warning systems over large areas.
- Design of a framework that allows for the use of different rainfall-runoff flood models linked to the Medium Range Weather Forecasts in order to provide Medium Range Flood Forecasts.
- Investigate the concept of an overall water balance hydrological model as a basis for regional rainfall-runoff flood modeling.
- Investigate the accuracy of the flood forecasts in space and time starting off from uncertainties in Medium Range Weather Forecasts and assess the error propagation through the system.
- Find methods to incorporate uncertainties both from the weather forecasts as well as from the hydrologic models to be used in operational forecasts and use them as a decision factor as part of the actual flood forecast.

- Investigation and recommendations concerning methods to disseminate the forecasts to which they might concern, and to retrieve feedback from the users.

National water authorities are normally able to provide flood warnings between one and four days in advance of flood events. These warnings are usually based on weather forecasts in combination with knowledge of the actual hydrologic conditions in the river basins concerned. However, the emergency civil and water management agencies would benefit from an increase in lead-time, to effectively implement their plans in downstream areas. Therefore, a need exists for improved flood forecasts to extend the flood-warning period. Improved flood forecasts should enable more effective evacuation of people from high-risk areas or the controlled release of water from reservoirs in upstream areas to create temporary retention basins to reduce flood volumes and peaks.

Recent developments in the art of weather forecasts have brought these needs for improved flood forecasts within reach. Currently, Medium Range Weather Forecasts are available for periods between 4 and 10 days ahead. These forecasts, which are still hardly used for practical purposes, should be taken advantage of by investigating the improvements that can be obtained in the present knowledge that is available to decision makers in flood-risk areas. In the present project, the reasonable extension of the forecast period will be examined by an assessment of the accuracy as a function of lead-time, location and season, and the minimum requirements put forward by the end-users.

5.10.2 Statistical versus deterministic methods

Flood forecasts are made using two methods:

<u>Statistical methods</u>

Statistical methods combine the boundary conditions (hydrologic conditions, meteorological forecasts and discharges upstream) to forecast water levels in the coming days. Such statistical methods are excellent tools for short-term forecasts, but they are less suited for forecasts more than a couple of days ahead.

<u>Deterministic methods</u>

Alternatively, the forecast can be based on a coupled meteorological-hydrologic model. If the hydrologic model is able to take changes in the hydrologic conditions in the river basin into account, such models are able to provide discharges over longer periods ahead.

The statistical method is evidently not applicable in the present project. For the deterministic method, the two main steps in the derivation of flood risks are weather forecasts and (subsequently) flood forecasts.

<u>Weather forecasts</u>

The main limitations on the weather forecast are the period for which the weather is to be forecast with accuracy. The spatial resolution of the forecast weather, mainly rainfall, is generally too coarse for use in forecast models more than a few days in advance. However, a few years' weather models have been developed that provide on a small resolution, a grid weather forecast more than four days in advance. Currently these forecasts can be provided for all of Europe. It is possible to couple these weather forecasts to hydrologic/flood routing models to allow for Medium Range Flood Forecasting.

The Siren project aims at defining, specifying and testing a dedicated service to manage and supply Earth Observation based information concerning flood risk. This service is oriented towards users involved in flood management, such as Disaster Management Services, Civil Protection bodies, Regional Authorities, and Ministries of the Environment.

5.11 Flood Forecasts Using SSM/I data

SSM/I data is obtained by the Defense Meteorological Satellite Program of the U.S. The SSM/I is a seven-channel, four frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0 and 85.5 GHz. The data are used to obtain synoptic maps of critical atmospheric, oceanographic and selected land parameters on a global scale. The SSM/I archive data set consists of antenna temperatures recorded across a 1,400 km conical scan, satellite ephemeris, earth surface positions for each pixel and instrument calibration.

Electromagnetic radiation is polarized by the ambient electric field, scattered by the atmosphere and the Earth's surface and scattered and absorbed by atmospheric water vapor, oxygen, liquid water and ice.

<u>Instrument description</u>

The SSM/I instrument consists of an offset parabolic reflector that is 24 x 26 inches fed by a seven- port horn antenna. The reflector and feed are mounted on a drum that contains the radiometers, digital data subsystem, mechanical scanning subsystem and power subsystem. The drum assembly rotates about the axis of the drum. A small mirror and a hot reference absorber are mounted on the assembly.

The instrument sweeps a 45^0 cone around the satellite velocity vector so that the Earth incidence angle is always 54^0. Data are recorded during the 102.40 of the cone when the antenna beam intercepts the Earth's surface. The channel footprint varies with channel energy, position in the scan, along scan or along track direction and altitude of the satellite. The 85 GHz footprints are the smallest with a 13 x 15 km and the 19 GHz footprints is the largest at 43 x 69 km. Because the 85 GHz footprints are so small, it is sampled twice, i.e., 128 times a scan. One data cycle consists of 4 scans of 85 GHz and 2 scans of the 19, 22 and 37 GHz channels. The complete cycle takes 28 seconds and it must be complete to process the data.

DMSP satellites are in a sun-synchronous, low altitude polar orbit. The orbital period is 101 minutes and the nominal altitude is 830 km.

<u>Processing</u>

The SSM/I processor is queried once a second by onboard computer and the data are placed into the "TS SSP" data field. Data is ingested in simple format as sent from AFWA on a T-1 line. At NGDC, the "TS SSP" data are decommutated, deinterleaved, bit flipped, reordered and restructured into orbits beginning with the equatorial crossing as the satellite travels from south to north.

Satellite ephemeris is computed using a physically based, orbital mechanics model. SSM/I pixels are geolocated using the satellite ephemeris and satellite attitude corrections. Antenna temperatures are computed from instrumental counts by a linear equation, i.e., the conversion is reversible.

In the decommutation step, bit reversals occurred 1.8 - 3.4% of the time, probably caused by ionospheric scintillation. These are identified through careful checking of procedures and corrected if necessary. Archive tapes contain an automated format statement, an orbital inventory, and metadata by orbit and geolocated antenna temperatures. A typical tape contains 8 days of data from two satellites.

Applications

SSM/I data are used to derive geophysical parameters; notably, ocean surface wind speed, area covered by ice, age of ice, ice edge, precipitation over land, cloud liquid water, integrated water vapor, precipitation over water, soil moisture, land surface temperature, snow cover and sea surface temperature.

Most current methods use statistical algorithms which mean or difference channel brightness temperatures (Hollinger et al., 1989). Brightness temperatures are computed from antenna temperatures using the published antenna pattern correction that includes dynamic adjustments for antenna side lobe, antenna efficiencies and neighboring pixel contributions. Future methods will be physically based using data from all atmospheric sensors on DMSP satellites, i.e., SSM/I, OLS, SSM/T and SSM/T-2.

Using SSM/I data, one can compute SWE and SWI as explained below. SWE gives information about liquid water content; from the status of snow melting, surface runoff and river levels can be monitored. Subsequently, a flood warning can be given. From a soil wetness index, information about the surface runoff and increase of river level and flooding can be obtained.

Using SSM/I data, the flood forecast can be made successfully after calculating Snow Water Equivalence (SWE) and Soil Wetness Index (SWI). These parameters are calculated from the following equations:

Snow Water Equivalence (SWE)

SWE (mm) = Kt * (Tb19.35H - Tb37H)

Kt depends on geographic location. For India, Kt = 1.

Soil Wetness Index (SWI) is an index, which is unitless and can be calculated from following formula

SWI = Tb85.5H - Tb19.35H

Where Tb19.35H, Tb37H and Tb85.5, are brightness temperature respectively, for 19.35, 37 and 85.5 GHz in horizontal polarization.

The Snow Water Equivalence (SWE) and Soil Wetness Index (SWI) maps over India are shown in Fig. 5-11-1 and Fig, 5-11-2. The SWE maps show the development of a sudden flood due to snow melting from the third week of September until the second week of October (blue region in the map). The SWI map shows the SWI for the months of July and August 1997 showing a likely flooded region. The likely flooded region shows the SWI in the range 28 – 50.

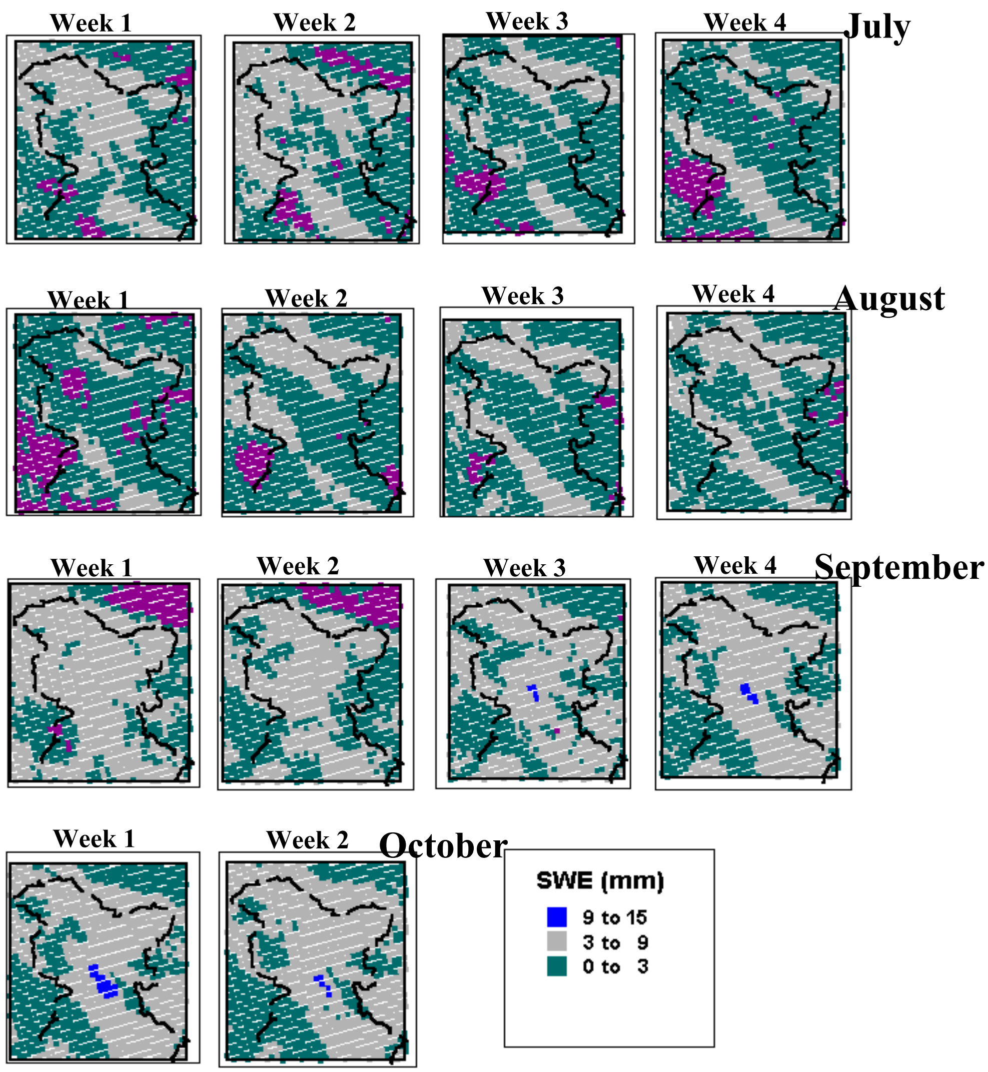
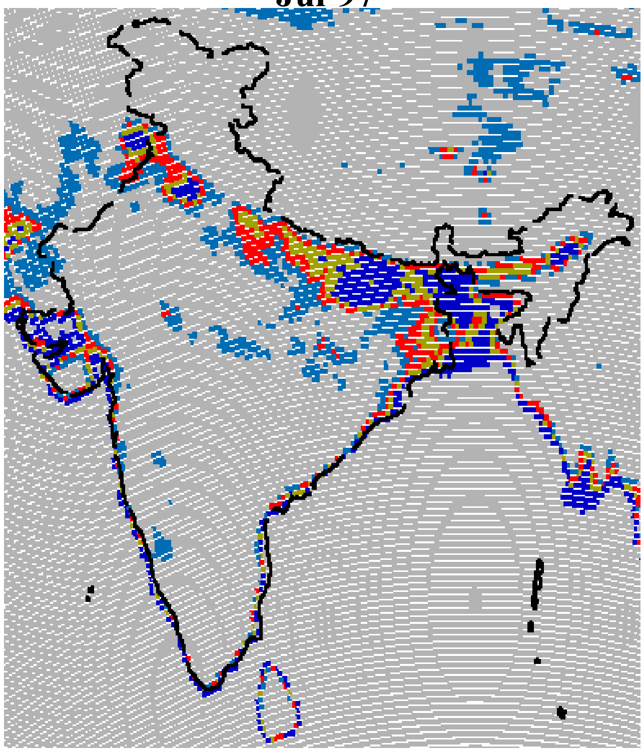


Fig. 5.11-1 Weekly averaged plots of SWE over the northern part of India for 1995

Jul-97



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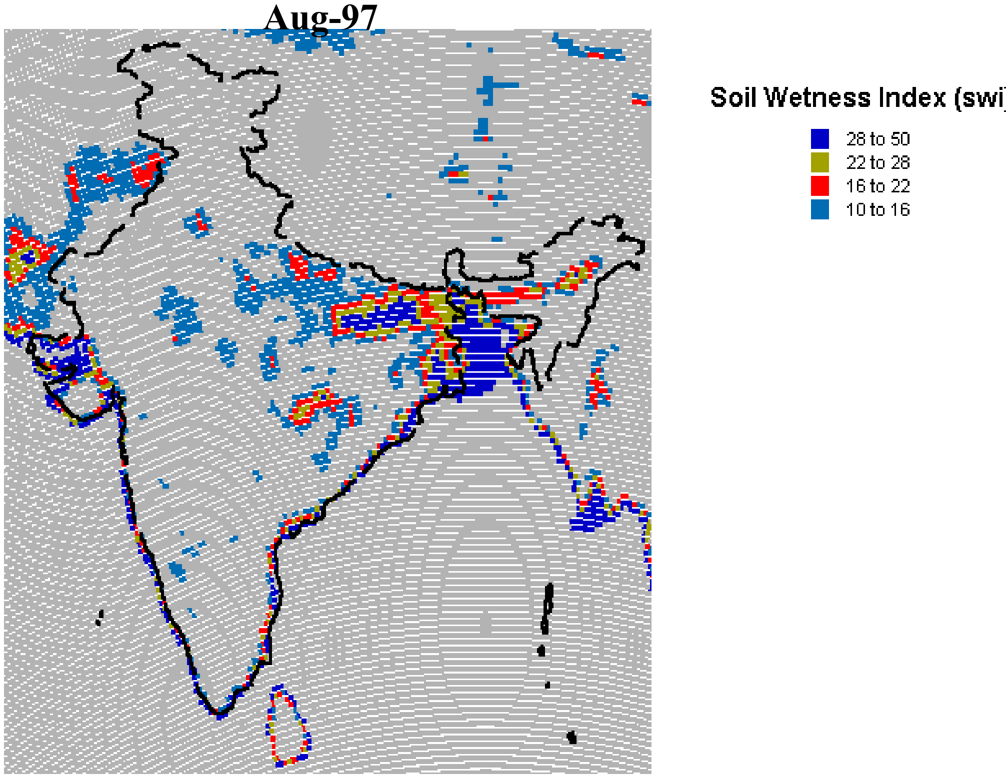


Fig. 5.11-2 Soil wetness index (SWI)

6 Flood forecasting and warning in developing countries

6.1 Flood forecasting and warning in Bangladesh

In developed countries, the average accuracy of forecasts of weather conditions is 80%. In developing countries, the average accuracy is very poor. The forecasts of weather should be improved in developing countries and as a result, flood forecasts will also improve. This will save lives and property in developing countries.

The purpose of a forecast center is to provide accurate predictions of water levels during the monsoon season for the whole country. Data on river flows and levels together with rainfall are transmitted to a center in Dhaka, which uses a sophisticated computer model to predict water levels in the rivers, and flooded areas and depths in the floodplains. The model should be updated on the basis of regular measurements to ensure its accuracy with respect to both the depth and time of flooding. The model is linked to a GIS to relate flood information to land use, population densities, infrastructure features, etc. The system provides different categories of warnings to each administrative region and to the government so that appropriate action can be taken. The information is also publicized through media channels, enabling local populations to seek shelter for themselves and their livestock before inundation occurs. With the advent of new and modern data processing systems, rural communities will gain access to warning systems and be able to participate in planning physical and other measures to alleviate flood events.

After experiencing numerous disastrous floods, the government of Bangladesh established a permanent Flood Forecasts Center in Dhaka in 1972. This center has moderate scientific personnel with a Chief Engineer, Hydrology and a Director, Processing and Flood Forecasting. This office is staffed with 22 persons. The center has received financial assistance from UNDP/WMO assistance from 1981 to 1986 and 1989 to 1992, along with scientific and technical assistance from Denmark from 1995 to 1997. The efforts of this center are to issue flood and cyclone forecasts and warnings through the Internet, E-mail, fax, telephone and wireless equipment, and also through radio and television. This center has following communication facilities:

- Voice data (HF Wireless network, 67 stations)
- Mobile telephone (3 stations)
- Telemetry System (14 stations)

Satellite data is also used for flood and cyclone forecasts and warnings. This center has access to GMS, NOAA-12 & NOAA-14 satellite data and imagery and uses on-line various meteorological data (rainfall, humidity, and water vapor) from Bangladesh Meteorological Department.

This center is using GIS techniques extensively to display water level and rainfall status (Flood Watch) that is being used for the forecast model. On a routine basis, this center generates water level and discharges and issues flood forecast bulletins.

This center uses a one-dimensional fully hydrodynamic model (MIKE 11 HD) incorporating all major rivers and floodplains that are linked to a lumped conceptual rainfall-runoff model (MIKE 11 RR), which in turn generates inflows from catchments within the country.

The total catchments area is about 82,000 sq. km; the total length of all rivers is 7,270 km; and the number of catchments is 216, all of which are monitored using 30 forecast stations. The routine flood maps are generated using flood forecast models via GIS link to MIKE 11 GIS.

The routine forecasts of floods (hydrographs) and meteorological parameters are available through a web page (http://www.ffwc.net). Fig. 6.1-1 shows the forecast stations and Fig.6.1-2 shows the hydrograph one can see through web page. The satellite images are classified in terms of the intensity of rainfall (heavy, moderate, light and no rain) and displayed through a web page (Fig. 6.1-3)

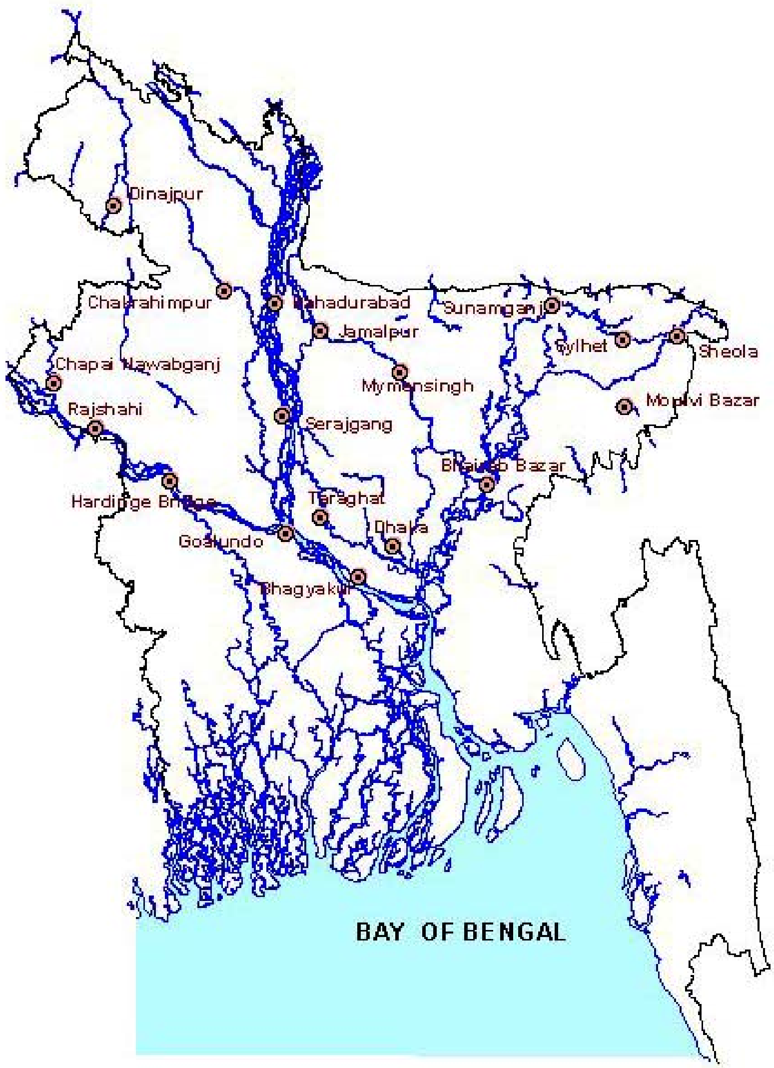


Fig. 6.1-1 Shows various forecast stations (Source: FFWC. 2001)

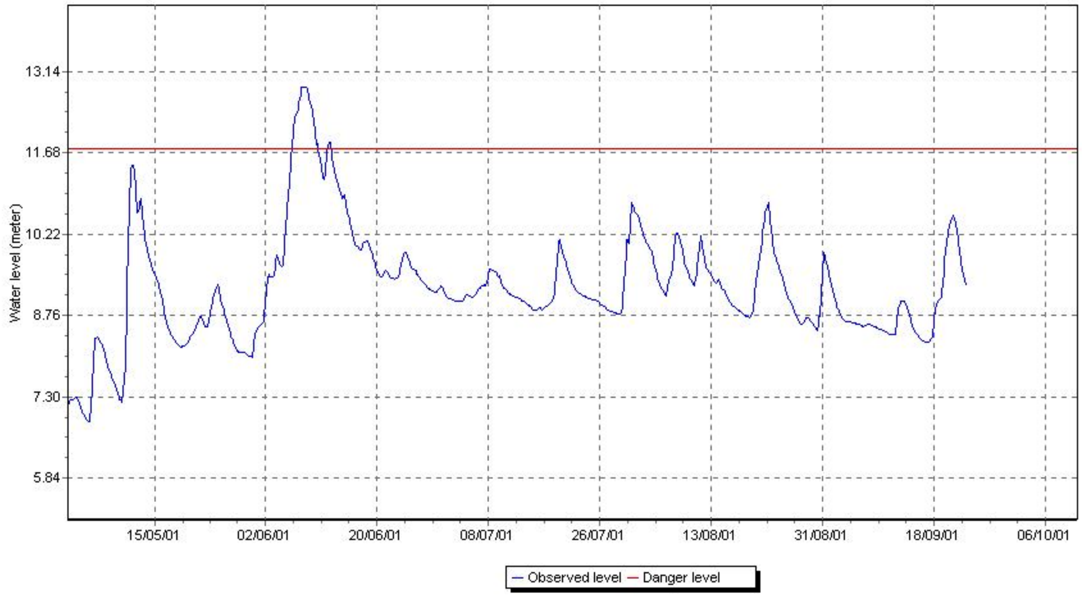


Fig. 6.1-2 Typical hydrograph see through web page (Source: FFWC, 2001)

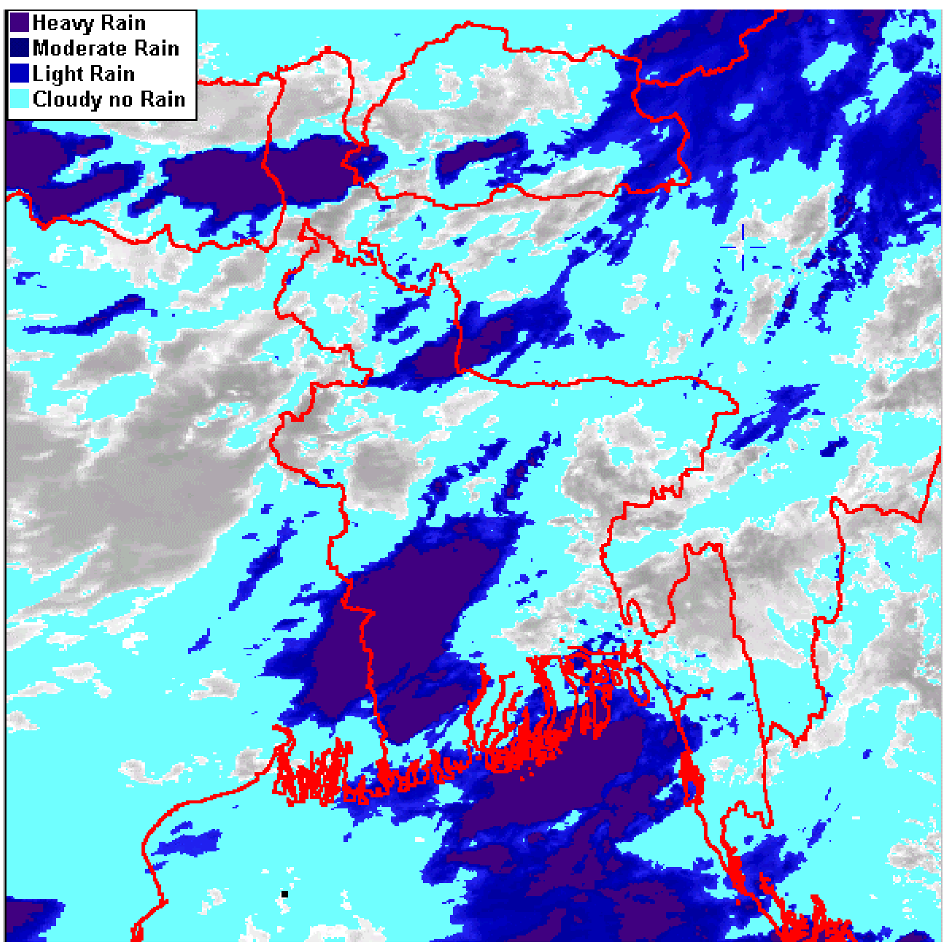


Fig. 6.1-3 Shows area with expected rainfall intensity (Source: FFWC, 2001)

Efforts are also made by the center to display inundation maps through the website that is given below (Fig. 6.1-4).

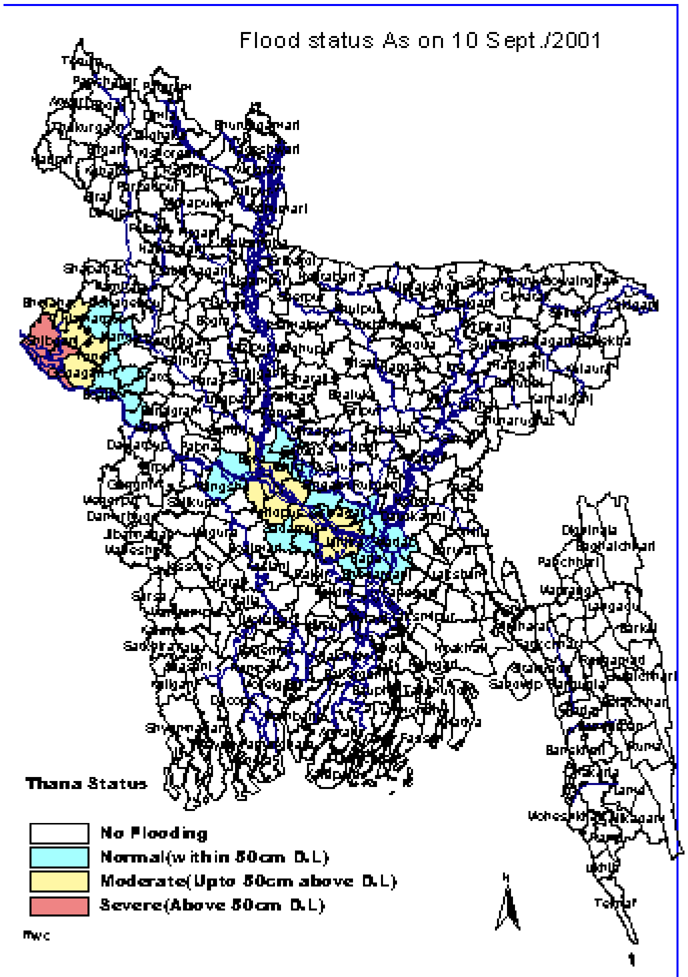


Fig. 6.1-4 Showing inundation map (Source: FFWC, 2001)

The Bangladesh Space Research and Remote Sensing Organization also forecasts weather conditions and meteorological conditions of Bangladesh using various satellites data. The information about this organization can be found through the website (http://www.sparrso.org/weather.html). A close cooperation by this organization and the Flood Forecast Center is essential in the reliable forecasts of flood in Bangladesh.

6.2 Flood forecasting and warning in China

<u>The South China Sea Monsoon Experiment (SCSMEX)</u>

The South China Sea Monsoon Experiment (SCSMEX) is a large-scale experiment to study the water and energy cycles of the Asian monsoon regions. The goal is to provide a better understanding of the key physical processes responsible for the onset, maintenance and variability of the monsoon over Southeast Asia and southern China, which in turn will lead to improved flood predictions.

The WMO/M1 Committee of Atmospheric Sciences, WCRP CLIVAR Monsoon Program and the Pacific Science Association jointly sponsor SCSMEX. It involves the participation of all major countries and regions of East and Southeast Asia, as well as Australia and the U.S. Visible images are available through Chinese Geostationary Satellite FY-II, which was launched on June 10, 1997. The strong convective activity over the South China Sea and the vicinity is noteworthy.

SCSMEX consists of five components:

- A pilot study component (1996-1998) - climatological data analysis, including satellite OLR, GPCP, re-analysis, pilot stations and mooring sites, planning of IOP strategies.
- A field experiment phase (May 1 to July 31, 1998) - routine and enhanced four times daily upper air sounding in stations around the SCS, hourly surface observations, ATLAS buoys, dual Doppler radar observations on ship and on islands, Integrated Sounding Systems, aerosondes, PBL measurements, air-sea fluxes, ocean survey ships.
- A satellite component (1996-2000) - rainfall estimates from TRMM, deep convective indices and cloud track wind, visible and IR cloud information from GMS and FY-II, surface wind from ERS-II, moisture data from SSM/I and sea surface temperature and outgoing long wave radiation AVHRR.
- A data analysis component (1998-2002) - analysis and interpretation of special and routine observations obtained during the field phase.
- Modeling component (1996-2002) - mesoscale model simulations, GCMs, nested mesoscale models global and regional 4-D assimilation.

The SCSMEX field phase is being closely coordinated with the GEWEX Asian Monsoon Experiment (GAME). In this program, dual Doppler radar coverage is collocated with an ATLAS buoy, which measures rainfall, surface meteorology and subsurface oceanic temperature and salinity. The TRMM satellite flying over the region provides spatial rainfall coverage on a broader scale over the SCS and the adjacent areas. With such a system, the forecasts of monsoons and various meteorological parameters may improve.

6.3 Flood forecasting and warning in India

Flood forecasting in India was started in 1959 by the Central Water Commission on the Yamuna River. Later, the flood forecasts program was extended to all major rivers and tributaries. Now, forecasts for 145 centers in the country are issued covering various river basins. In 1980 with the assistance of UNDP, an improved River and Flood Forecasts System in India began as a pilot plan on the Yamuna River. The system was tested during the1985 monsoon season, when the data was collected automatically at different sites and transmitted to the Central Station at Delhi through VHF links. These data are processed at CWC and a forecast was issued. At present, flood forecasts are formulated with the help of multiple correlation diagrams in which the actual river stages at the base and forecast stations, the rainfall in the intervening catchments with appropriate antecedent precipitation index, and the stages of the tributaries joining the river between the base and the forecast stations are the parameters. In the last three decades, significant progress in flood forecasts in India has been made. A flood forecast program now covers all major interstate rivers in the country. At present, data from about 350 hydrological sites and the 500 meteorological stations are included in the programme for collecting data for forecasts. Data are transmitted to analysis centers over radiotelephones by a network of 450 wireless sets.

Data Collection Network and Communication Systems

An up-to-date and reliable hydro-meteorological and hydrological database is a basic prerequisite for any effective flood disaster management activity. For the Brahmaputra basin with its enormous untapped resources potential, inaccessible and rugged terrain condition and inadequate scientific database, there is an imperative need to strengthen and update the technological, institutional and infrastructure aspect of data collection, transmission and processing. Given the international character of the basin, spread over several large populous countries, there is an overriding necessity for development of regional as well as international cooperation in various water resources assessment activities. Standardizing and upgrading data acquisition, transmission and processing procedures through development of appropriate technological and manpower base and networking facilities should greatly help in the effective management of flood hazards and utilization of the water resources in rivers like the Brahmaputra.

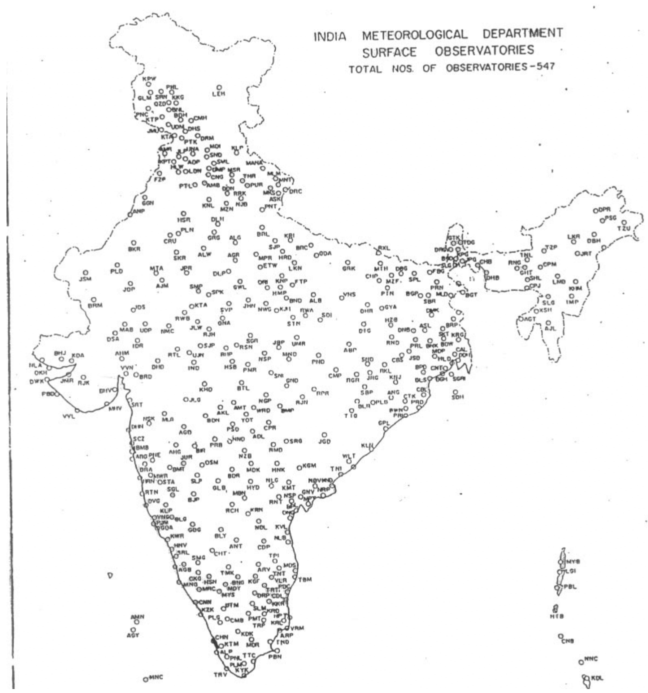


Fig. 6.3-1 Shows density of meteorological stations in India

For the purpose of flood forecasting and warning, the Central Water Commission (CWC) through a network of rain gauge stations routinely collects hydro-meteorological and hydrological data on the Brahmaputra sub-watersheds and the mainstream. The Indian Meteorological Department (IMD) and few state government departments including Agriculture, Irrigation and Flood Control also maintain their network of hydro-meteorological stations. Fig. 6.3-1 shows the density of meteorological stations in India. For the measurement of rainfall, both ordinary and self-recording rain gauges are being used although the network is rather sparse, especially in regard to self-recording rain gauges and the upper catchments of the rivers. According to an estimate made in 1993, there were 336 ordinary rain gauges and 113 self-recording rain gauges in the Brahmaputra catchments covering India and Bhutan with a total area of 240,000 sq. km. However, the density of the network, especially in the case of self-recording rain gauges, was found low as per the WMO suggested norm (WAPCOS, 1993). A current estimate indicates there are about 300 ordinary rain gauges and 100 self-recording rain gauges in the Indian part of the Brahmaputra basin. The Indian Meteorological Department (IMD) maintains 74 ordinary and 61 self-recording stations, while government departments of different states including Assam maintain 167 ordinary rain gauges. The Brahmaputra Board maintains 60 ordinary and 30 self-recording gauges, and the NF Railways 5 ordinary rain gauges.

The network of rain gauges remains inadequate in the mountain region. The monitoring of flow in the Brahmaputra basin is maintained by a network of water gauging stations is the Central Power Commission in collaboration with the state Flood Control Department. Currently there are six major gauge stations on the Brahmaputra where stage, discharge and sediment measurements are carried out on a daily basis. On most tributaries, there are more than 50 rain gauge stations, the major tributaries having at least one site on the upstream and one on the downstream section. The density of the existing network, especially in the upper catchments of the rivers, is rather sparse. The water levels are measured using conventional methods. Automatic gauging of water levels is not yet done on a routine basis on the river. The flood water level data are transmitted mainly through wireless and occasionally through telephone, telegraph or fax.

In India, there are 3,037 reporting rain gauges and 5,801 non-reporting rain gauge stations used to observe rainfall. Apart from ground stations, a voluntary observing fleet of 207 Indian ships is used. For transmission of hydro-meteorological and hydrological data from the rain gauge stations, the CWC depends mainly on a wireless network dedicated for the purpose. However, land line communications using telephone, telegraph and fax facilities are also used wherever available. Flood warnings are made mainly on the basis of travel time between the selected base station and the particular forecast station and the rain-gauge-to-rain-gauge correlations of water levels. The lead-time for the forecasts varies depending on the travel time between the concerned rain gauges being used. For the mainstream of the Brahmaputra the lead-time is up to 112 hours. During the period of high floods, flood-warning messages are broadcast through local radio and television centers and also through the printed media. The information is also supplied to the various user agencies or departments. Although the technology of satellite telemetry is available in the country, is not yet being used on operational basis for flood forecasts activities in the Brahmaputra basin.

Methods used in flood forecasting and dissemination of information

The data transmitting capability of modern satellites has immense potential for hydrological applications, especially in the area of flood forecasts. The geostationary weather communications satellite of India called INSAT belongs to this category of satellites which has onboard Data Collection System (DCS) that transmits data received from ground based Data Collection Platforms (DCP) to the computerized data processing facilities. Commonly used hydrological variables such as water stage, flow, precipitation, etc. can be interfaced with DCPs and relayed via satellite to the analysis centers for timely dissemination of early warning and real-time coordination of relief operations. One hundred meteorological data collection platforms have been installed throughout the country. The Central Water Commission has also deployed 15 DCPs in the Yamuna catchments for flood forecasts. The advent of Very Small Aperture Terminals (VSAT) and Ultra Small Aperture Terminals (USAT) has further increased the capability by providing low cost, viable technology that can be used for disaster mitigation and management. A fully automatic operational flood forecasts system is being tested in a pilot project conducted in the Yamuna basin near Delhi. With the availability of multiple satellite data from IRS, Landsat, ERS and Radarsat, India has made considerable progress in recent times in mapping and monitoring flood episodes in near real-time in selected watersheds including the Brahmaputra in Assam. Both optical as well as microwave data from different sensors such as WiFS, LISS III and PAN from IRC IC and ID, TM data from Landsat-5 and microwave data from ERS and Radarsat are being used for the purpose. The data obtained from the wide field sensor called WiFS onboard IRS-IC and ID satellites prove to be particularly useful in flood studies due to their large swath and higher receptivity. The Disaster Management Group of the Department of Space, Government of India is currently leading the country in near real-time mapping of floods and assessment of damage in selected watersheds, in collaboration with relevant state government departments/agencies such as the Remote Sensing Application Centers, the Department of Agriculture, and the Department of Revenue. The data and information on inundation and damage due to floods are made available to the concerned state departments for making reliable estimates of damage and organizing necessary relief measures.

Recent exercises carried out in the country indicate that the introduction of remote sensing inputs such as satellite-based rainfall estimates, landuse/land cover, soil status, etc. in the rainfall-runoff models and integration of these databases under GIS environment considerably improves flood forecasting capabilities. Similarly, use of satellite-based data during pre-flood, flood and post-flood periods along with conventional ground information provides more reliable and timely assessment of damages.

Initially, flood forecasts in the country were based on a simple graphical correlation between upstream and downstream gauge stations. Later, rainfall and rain gauge/discharge data of tributaries, etc. were also incorporated. In certain cases, application of unit hydrograph and flood routing models were also used. Efforts to develop suitable mathematical models were started during the 1980s. The modified version of the SSARR model was developed for the Yamuna River and the NAM model was developed for the Damodar River. Several other models such as TANK, NWSH, HBV, etc. are also currently being used. These exemplify the countrywide endeavor being made in government agencies and educational institutions to develop suitable flood forecast models. However, in the case of the Brahmaputra, no major effort on mathematical modeling for the purpose of flood forecasts and disaster mitigation has been undertaken so far.

Institutional arrangements for flood forecasts adopted so far in the country, especially with regard to the Brahmaputra basin, needs to be revamped and reorganized so that flood forecasts and warning activities are done more efficiently using state-of-the-art technology. The research and development components in existing organizations involved in flood forecasts need to be upgraded with respect to technology and manpower base. Educational institutions presently offering or planning to offer scientific courses or training in the area of flood forecasts should be strengthened. Introduction of private entrepreneurship and involvement of NGOs may also contribute to more effective management of flood disasters including flood forecasts and warning activities. There is a pressing need for institutional changes to develop a network of hydrological and hydro-meteorological stations through cooperation and coordination on national and regional scales, including standardization of instrumentation and methodology. There is also a pressing need to ensure better accessibility to existing hydrological and hydro-meteorological databases, especially in regard to a large, underdeveloped watershed like the Brahmaputra River. More efficient and wider dissemination of information in regard to flood disaster management is a matter of great urgency where the attention of concerned national governments and international agencies should be further focused.

Little written information and data are available on the accuracy level of flood forecasts. Available records indicate that in the early 1990s, a forecast was considered to be reasonably accurate if the observed water level fell within 15 cm of the forecasts level (Rao, 1989). Flood forecasts currently issued by CWC using conventional rainfall-runoff models have an accuracy of 65-70% with a warning time of six to twelve hours (Rao, 2000). Inadequacy in the rainfall gauge network and lack of sufficient data on basin parameters are the major causes behind lower accuracy level of the forecasts. Encouraging results have been obtained in a pilot study carried out in the lower Godavari basin where satellite remote sensing, GIS and GPS technologies were used in conjunction with ground observations. In this case, the deviation of the flood forecasts from observed floods was estimated to be within 15 percent.

Existing cooperation agreements

In the area of flood forecasting and warning there is extensive cooperation between various concerned departments of the Central Government and affected state governments. Although CWC is primarily responsible for flood forecasts and warning activities in the country, several other central government departments and agencies including the IMD, DOS, Ministry of Agriculture, and Ministry of Irrigation together with state government departments such as Agriculture, Revenue, Flood Control, and Irrigation are involved. In the case of the Brahmaputra River, the Brahmaputra Board is expected to play a significant role in the management of flood hazards and utilization of river water resources within the basin. The Brahmaputra is a major international river with very significant upstream-downstream linkages, and there is an imperative need for cooperation and coordination among the different countries sharing the river, especially in regard to flood management. However, there is no such existing cooperation agreement between the riparian nations sharing the watershed.

Lesson Learned in Flood Forecasting

Although there have been frequent floods of great magnitude affecting millions of people and causing immense damage to public property and infrastructure, in the absence of any existing agreement among the concerned countries regarding sharing of data and information on water resources, the efforts made so far in individual countries in the area of flood forecasting and warning have been only partially successful and less than effective. Inadequacies in the monitoring network and lack of desired level of sophistication and standardization in data acquiring, transmission and processing techniques have widely been realized now by scientists, technologists, planners and decision makers. Lack of accessibility and transparency with regard to hydrological data, especially on international rivers like the Brahmaputra, proves detrimental to the development and expansion of research and development activities on water-related issues including flood forecasts and warnings. Considerable growth of bureaucratization as well as centralization of power and resources in the management of water resources have hampered flood forecasting efforts. There is a definite need for change in policy, reorientation of strategy and revamping or establishment of institutions for development of efficient flood forecasts and warning systems. Figs. 6.3-2 and 6.3-3 show storm detection radar and cyclone warning radar networks in India. This radar is very useful in forecasting storms and cyclones and helps the country decide whether to evacuate coastal areas.

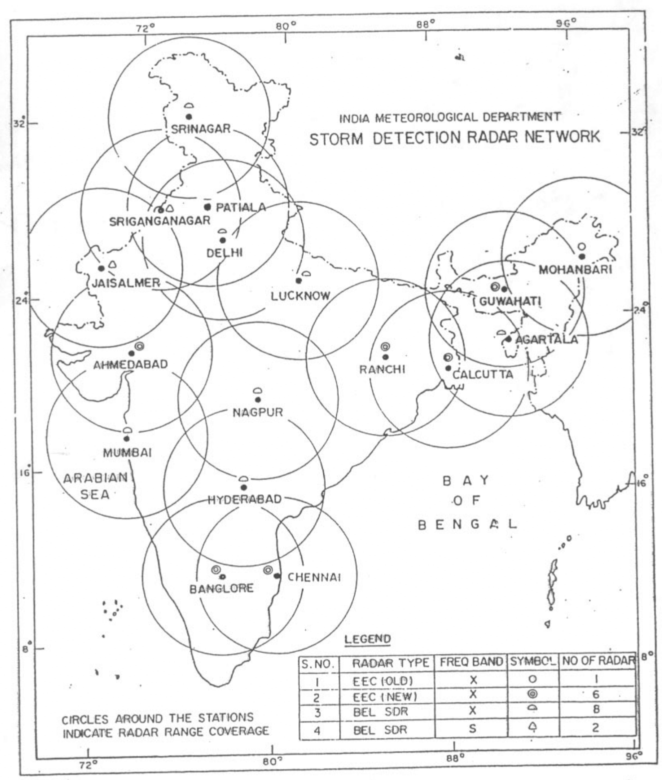


Fig. 6.3-2 Shows storm detection radar and cyclone warning radar networks in India

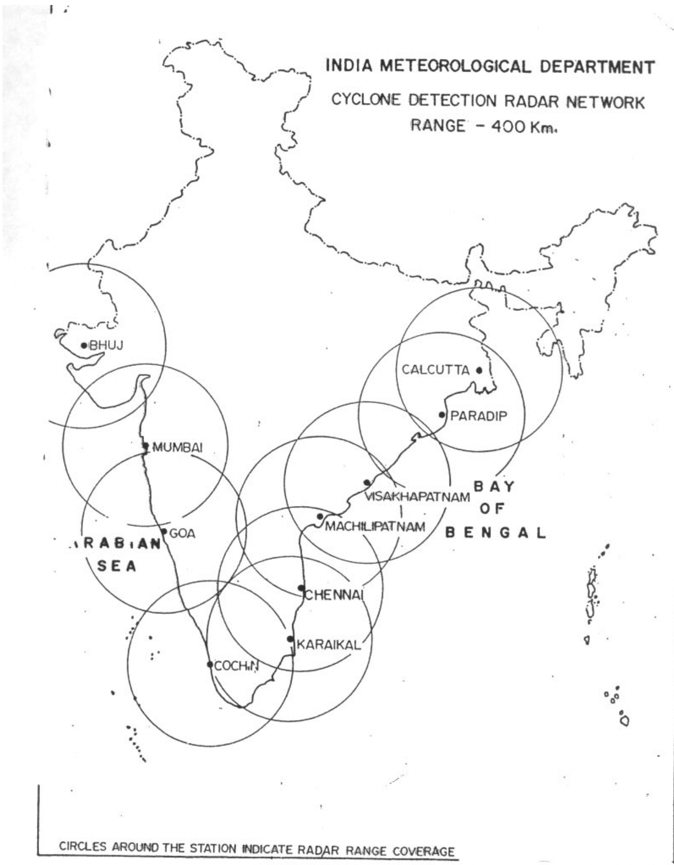


Fig. 6.3-3 Shows storm detection radar and cyclone warning radar networks in India

Seasonal Prediction of Indian summer Monsoon

The Indian summer monsoon controls the rainfall over India and Bangladesh. The prediction of the onset and magnitude of Indian summer monsoon is of paramount importance in flood forecasts and climatic conditions. To achieve a reliable and accurate prediction of the Indian summer monsoon, understanding the influence of various other parameters and their interdependence are required. In 1875, the National Meteorological Services of India was established to undertake a systematic study of weather and climate in the subcontinent. The information was used to issue forecasts and warnings during the summer monsoon. Indian summer monsoon has shown a considerable inter-annual and inter-seasonal variability and years of droughts and floods have occurred occasionally in successive years (1917 and 1918, 1987 and 1988). Monsoons are a quasi-global perturbation in the general circulation of the atmosphere. Understanding its regional characteristics over Africa, China, and India and in other parts of the world affected by the monsoon regime needs constant effort. Forecasting monsoon rains on different space and time scales is a challenging task. In recent years, considerable knowledge has been acquired and is being used with respect to ENSO and their global influence in modulating the rainfall and circulation in the tropics. In 1990, the World Hydrological Cycle Observing System (WHYCOS) was set up to collect data. From this, WMO supports the collection and dissemination of water related data and information from an integrated system of regional and global networks of observing stations using modern technology (Fig.6.3-4).

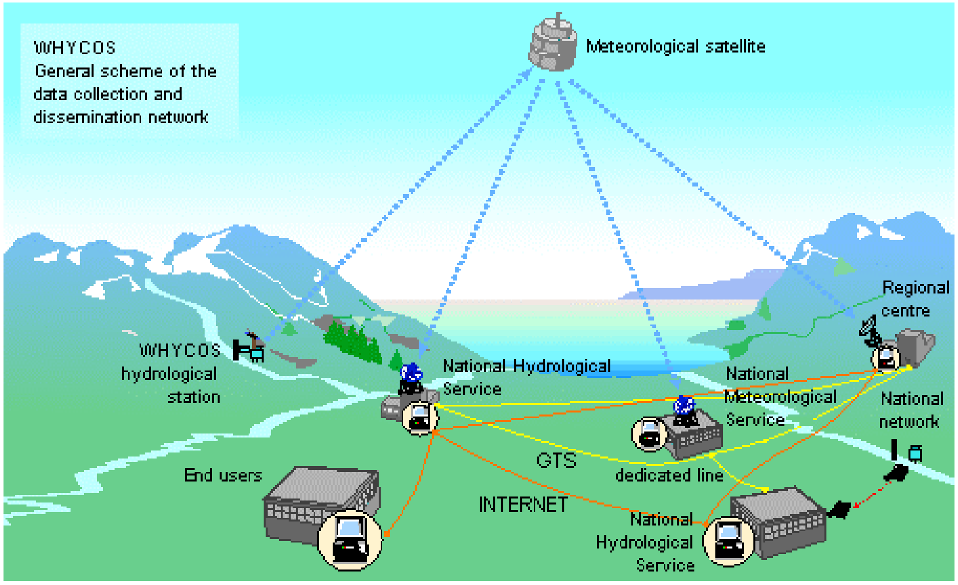


Fig. 6.3-4 WHYCOS general scheme of data collection and dissemination network (Source: WHYCOS, 2001)

6.4 Other countries and regions

6.4.1 Floods in Pakistan

The total geographical area of Pakistan is 796,000 sq. km. and can be broadly divided into three hydrologic units: the Indus basin, which covers nearly 70% of the country's area; the Kharan desert; and the Makaran arid and coastal area, which almost evenly constitute the rest. The main water resource in Pakistan is therefore the Indus basin with a total drainage area of 965,300 sq. km, of which 58% lies in Pakistan and the rest in India, China and Afghanistan.

6.4.2 Flash floods in the Indus river basin

Heavy concentrated rainfall in the catchment during the monsoon season, which is sometimes augmented by snowmelt flow and rainfall primarily outside the Indus plain, generally causes floods. Monsoon currents originating in the Bay of Bengal and subsequent depressions often result in heavy downpours in the Himalayan foothills and Koh Hindukush, occasionally producing destructive flash floods along one or more of the main rivers of the Indus system. In some cases, exceptionally high floods have been caused by the formation and subsequent collapse of temporary natural dams from landslides or glacier movements. The Federal Flood Commission has been functioning as a Federal Agency on a national basis since 1977 to design, execute and monitor a National Flood Protection Plan to mitigate flood damage and safeguard human life and property.

6.5 Stream Flow Model for Africa

The Famine Early Warning System Network (FEWS NET) in cooperation with the USGS/EROS Data Center has undertaken efforts to enhance flood preparedness. Through the use of hydrologic modeling techniques, it is possible to better predict and react to such events. The FEWS NET Stream Flow Model (SFM) (Fig. 6.5-1) is a geospatial model based on the use of satellite remote sensing, numerical weather forecast fields, and geographic data sets describing the land surface. The model is currently operational in Southern Africa, and implementation will soon cover all basins of concern to the 17 FEWS NET countries.

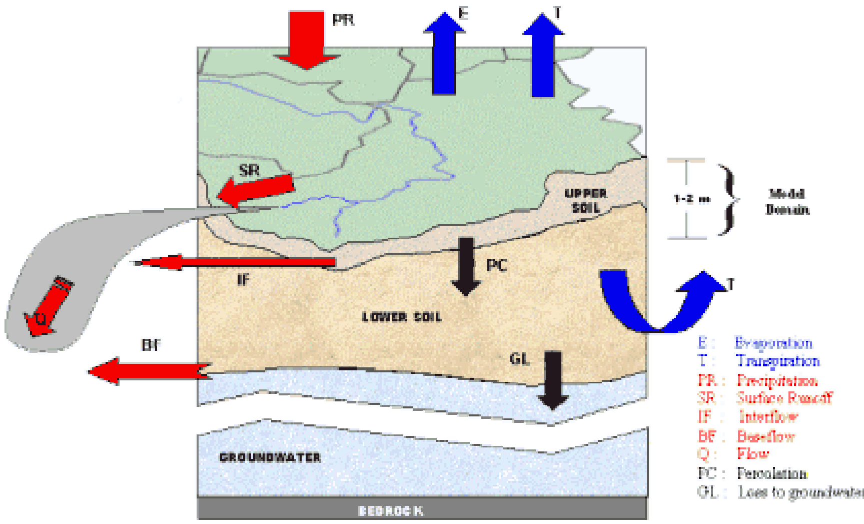


Fig. 6.5-1 Conception of the Stream Flow Model (SFM) (Source, USGS, 2001)

The FEWS NET hydrological model was developed by the USGS/EROS Data Center to provide a continuous simulation of stream flow, on a daily time step, for approximately 5,600 basins on the African continent. Mean basin area in the Southern Africa region is approximately 3,500 km^2. The model is a physically-based catchments scale hydrologic model (semi-distributed hydrologic model). It consists of a GIS-based module, used for model input and data preparation, and the rainfall-runoff simulation model. The rainfall-runoff model is comprised of a soil and water accounting module that produces surface and sub-surface runoff for each sub-basin, an upland headwater basins routing module, and a major river routing module.

<u>The runoff prediction module conceptualizes the soil as composed of two main zones:</u>

- An active soil layer where most of the soil-vegetation-atmosphere interactions take place.
- A groundwater zone.

The active soil layer is divided into an upper thin soil layer where evaporation, transpiration, and percolation take place, and a lower soil layer where only transpiration and percolation occur.

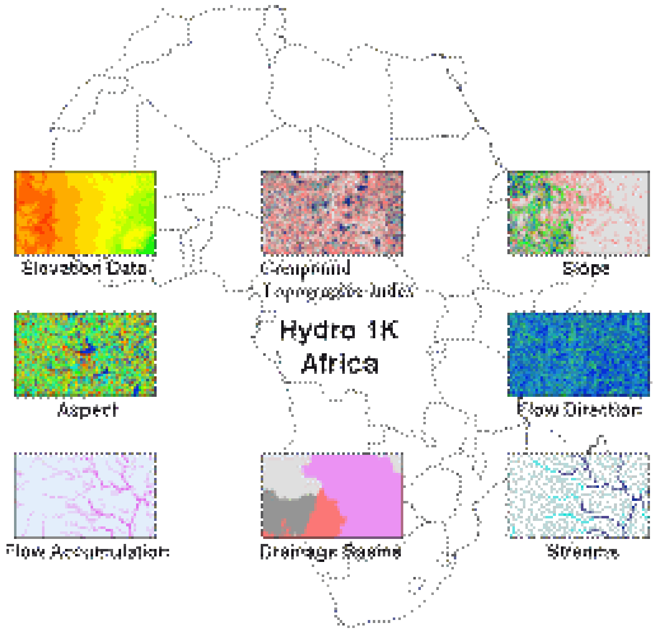


Fig. 6.5-2 Stream Flow Model Inputs (Source, USGS, 2001)

6.5.1 Topography

GTOPO30 global topographic data set (Gesch et al., 1999) describes the continents with elevation values at a regular spacing of 30 arc seconds of latitude and longitude. Preparation of hydrologic derivatives from GTOPO30 by USGS (1999) yielded the HYDRO1K data set consisting of basin delineations and stream networks bearing topological identification numbers, as well as grids of flow direction, flow accumulation, slope, and other variables. HYDRO1K basins and streams provide the spatial framework for the FEWS NET SFM.

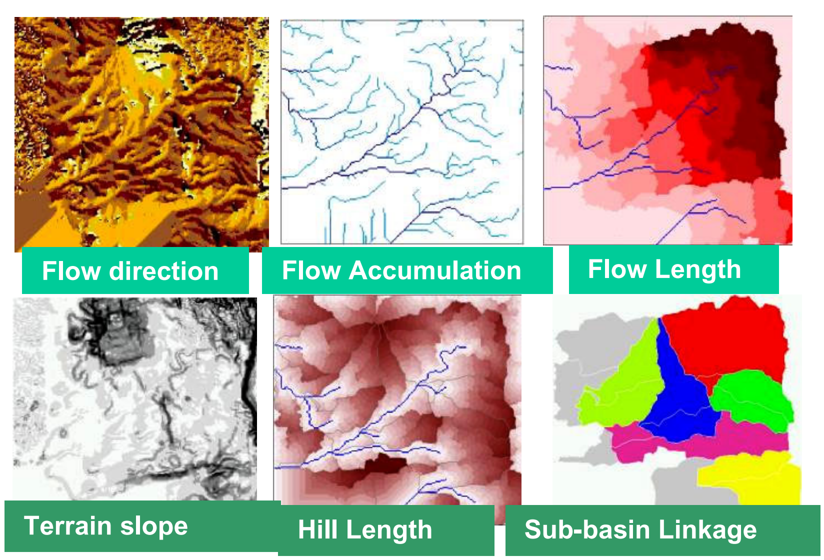


Fig. 6.5-3 Other Derivatives of USGS 1 km DEM (Source: USGS, 2001)

The runoff-producing mechanisms considered in the model are surface runoff due to precipitation excess (including direct runoff from impermeable areas of the basin), rapid subsurface flow (interflow), and base flow. The model has an upland headwater basin routing module and a major river routing module. The surface upland routing routine is a physically based unit hydrograph method that relies on cell-based landscape attributes such as drainage area, slope, flow direction, and flow length derived from a digital elevation model. The interflow and base flow components of the runoff are routed with a set of theoretical linear reservoirs. In the main river reaches, water is routed using a nonlinear formulation of the Muskingum-Cunge routing scheme. Most of the model parameters have a physical meaning and are determined by the spatial distribution of basin characteristics. Parameterization of the basin's hydrologic properties is accomplished through the use of three data sets describing the Earth's surface: topography, land cover, and soils. Currently, a fifth level Pfafstetter subdivision (Verdin and Verdin, 1999) derived from the GTOPO30 global topographic data set is used to define sub-basins and model the African continent.

6.5.2 Land Cover

Using land cover for Africa derived from 1-km satellite data (Loveland and Belward, 1997), in conjunction with soils information, rainfall incidence on a basin is partitioned to separate surface runoff from water infiltrating into the soil. A twelve-month time series of 1-km vegetation index imagery was the primary basis for classification of land cover types (Fig. 6.5-3).

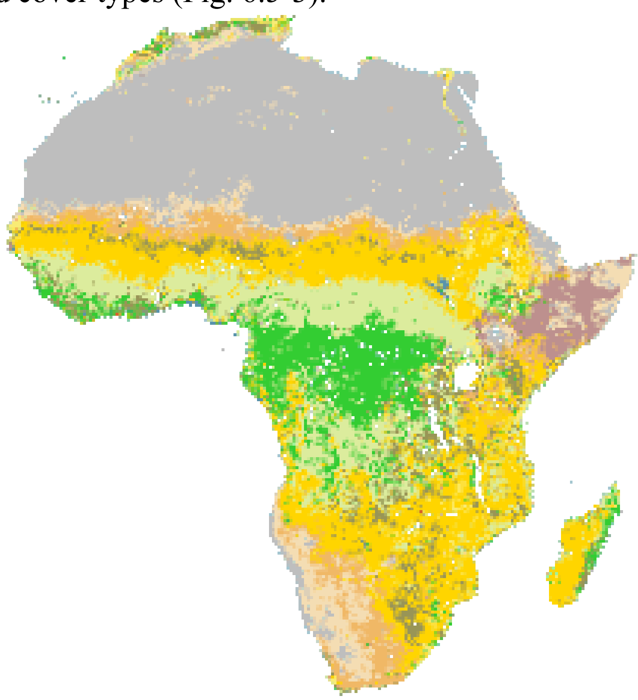
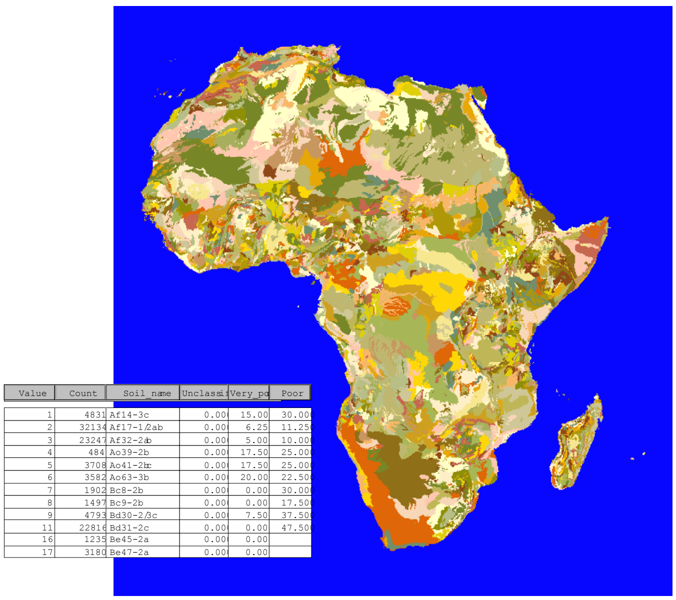


Fig. 6.5-4 Land cover in Africa (Source: USGS, 1995)

6.5.3 Soil

The Digital Soil Map of the World (FAO, 1997) was derived from an original compilation at a 1:5,000,000 scale. Attributes for soil associations are used by the SFM to set hydraulic parameters that govern interflow, soil moisture content, and deep percolation to the ground water table. Rates at which subsurface layers release water to the stream network also depend on these physical soil attributes.



Value	Count	Soil_name	Unclassi	Very_po	Poor
1	4831	Af14-3c	0.00	15.00	30.00
2	32134	Af17-1/2ab	0.00	6.25	11.25
3	23247	Af32-2ab	0.00	5.00	10.00
4	484	Ao39-2b	0.00	17.50	25.00
5	3708	Ao41-2bc	0.00	17.50	25.00
6	3582	Ao63-3b	0.00	20.00	22.50
7	1902	Bc8-2b	0.00	0.00	30.00
8	1497	Bc9-2b	0.00	0.00	17.50
9	4793	Bd30-2/3c	0.00	7.50	37.50
11	22816	Bd31-2c	0.00	0.00	47.50
16	1235	Be45-2a	0.00	0.00	
17	3180	Be47-2a	0.00	0.00	

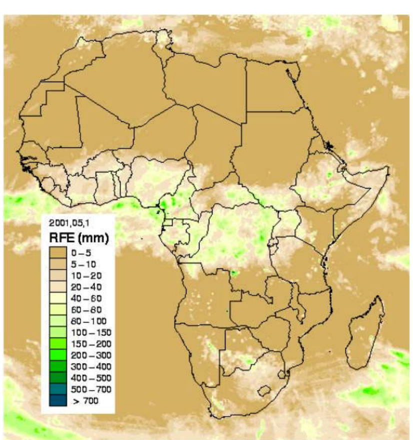
Fig. 6.5-5 FAO Digital soil map of Africa (Source: FAO, 1999)

6.5.4 Model Forcing

Daily variations in weather drive the calculation of stream flow estimates. Fluxes of water between the atmosphere and Earth's surface are described using geospatial estimates of precipitation and evaporation.

6.5.5 Satellite Rainfall Estimates (RFE)

(a)



(b)

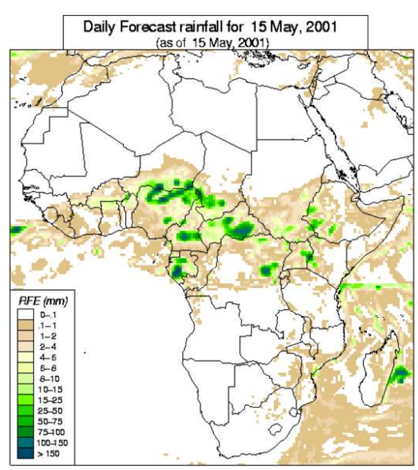


Fig. 6.5-6 (a) Current Rainfall Estimate, NOAA. (b) Quantitative Precipitation Forecast, AFWA.

Satellite rainfall estimates are of fundamental importance for geospatial stream flow modeling. They describe the spatial distribution of precipitation, which the SFM uses to determine the gross input of water to each basin for each day. NOAA/CPC (Climate Prediction Center) has provided dekadal RFE for Africa since 1995 (Herman et al., 1997). Since 1998, daily RFE have been provided, and in 2000, a new method based on Xie et al. (1997) was introduced.

6.5.6 Integrating Satellite Rainfall Estimates with Digital River Basin Maps

Excess precipitation and flooding can adversely affect food security through reduced crop production and disrupted transportation and market systems. Efforts have focused on new methods of analyzing the spatial and temporal patterns of precipitation to identify these situations. NOAA's Climate Prediction Center produces gridded rainfall estimates (RFE) for FEWS through processing Meteosat imagery, rain gauge data, and model estimates of wind and relative humidity. USGS scientists have developed methods for spatial integration of the RFE over topologically linked river basins derived from a 1-km digital elevation model. These accumulations are compared with long term average values to derive a flood risk score. Cartographic products with color-coded basins and drainage networks are made to highlight areas with high scores. Comparison of these products with reports from disaster relief agencies and the press show the correlation of prolonged heavy rainfall associated with flooding and the disruption of human activities.

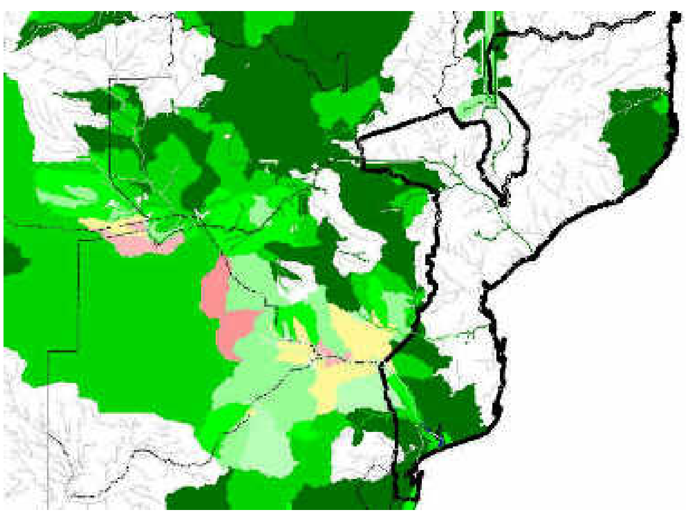


Fig. 6.5-7 Integrating Satellite Rainfall Estimates with Digital river basin Map (source: USGS, 2001)

The disastrous floods in Mozambique during February and March of 2000 are illustrated, including the importance of heavy rains that fell in upstream areas outside the country. A companion product was a map of estimated runoff travel times, using digital elevation data and an approximation of the Manning equation for flow in an open channel.

In Basin Excess Rainfall Maps, the catchment map highlights sub-basins (out of approximately 3,000 across the continent) receiving above-average precipitation for the dekad by color coding the relevant polygons. The scale is a scoring system that uses both total rainfall and total cumulative rainfall over a sub-basin for the dekad, divided by the same variable for long term average conditions. The greater the ratios, the higher the score.

The river (or stream) map highlights the reaches of the river receiving above-average amounts of dekadal precipitation according to a similar scoring system. The difference is that a reach of the river may receive rainfall from a much larger upstream area than that of the sub-basin polygon in which it lies. Thus, a sub-basin may not be highlighted because only light rain is occurring locally, while the reach of river passing through it is highlighted, due to heavy rains in upstream catchments.

6.5.7 Potential Evapotranspiration (PET)

Potential evapotranspiration represents atmospheric demand for water from the Earth's surface as a function of solar radiation, air temperature, wind, humidity, and atmospheric pressure. PET is essential for the calculation of a daily basin water balance.

The USGS has developed routines for ingest of grids for the input variables as produced by NOAA's Global Data Assimilation System (GDAS) on a 1-degree grid. PET is then calculated on a cell-by-cell basis according to the Penman-Monteith equation (Shuttleworth, 1992; Verdin and Klaver, 2001). Grids are produced on a daily time step for use with the FEWS NET stream flow model.

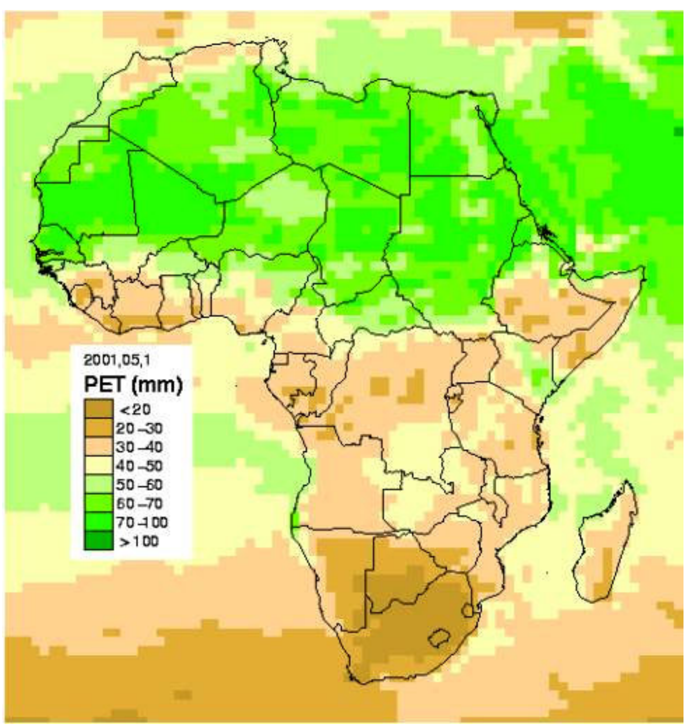


Fig. 6.5-8 Potential Evapotranspiration (Source: EROS Data Center, 2001)

6.5.8 Stream Flow Model Flow Chart

The FEWS hydrological model was developed by USGS scientists to provide a continuous simulation of stream flow, on a daily time step, for nearly 3,000 basins on the African continent. Mean basin area in the Southern Africa region is approximately 5,400 km^2. The model is a physically based catchment scale hydrologic model (semi-distributed hydrologic model). It consists of a GIS-based module used for model input and data preparation, and the rainfall-runoff simulation model. The rainfall-runoff model comprises a soil and water accounting module that produces surface and sub-surface runoff for each sub-basin, an upland headwater basins routing module, and a major river routing module (http://edcnts11.cr.usgs.gov/gflood/images/moz03.jpg).

The runoff prediction module conceptualizes the soil as composed of two main zones: (a) an active soil layer where most of the soil-vegetation-atmosphere interactions take place, subdivided into two-layers; and (b) a groundwater zone. The active soil layer is divided into an upper thin soil layer where evaporation, transpiration, and percolation take place, and a lower layer where only transpiration and percolation take place. The runoff producing mechanisms considered in the models include surface runoff due to precipitation excess (including direct runoff from impermeable areas of the basin), rapid subsurface flow (interflow), and base flow. The three linear reservoirs are for surface runoff, rapid sub-surface flow, and groundwater routing. For routing in the main river reaches, a nonlinear formulation of the Muskingum-Cunge channel routing scheme is used.

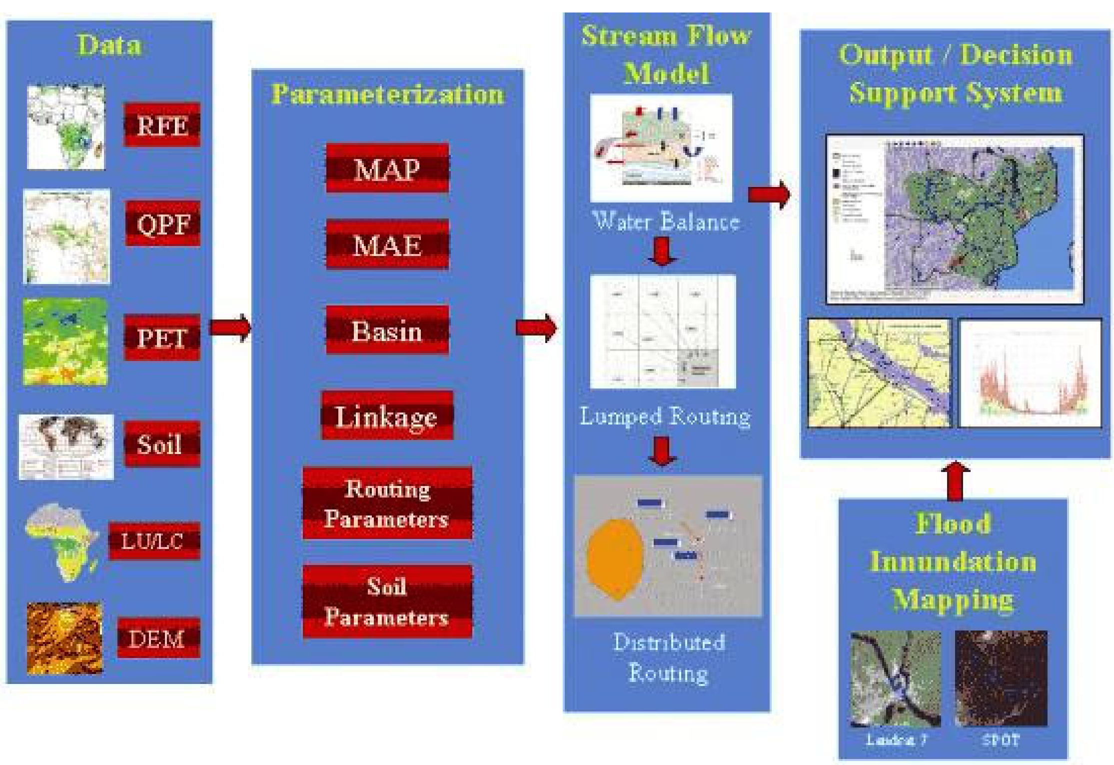


Fig. 6.5-9 FEWS Flood Risk Monitoring System Flow Diagram (Source: USGS/EROS Data Center, 2001)

6.5.9 Data

Important data sets required by the model include:

- USGS HYDRO1K database (http://edcdaac.usgs.gov/gtopo30/hydro), a derivative of the USGS digital elevation database (http://edcdaac.usgs.gov/gtopo30/gtopo30.html);
- USGS global land cover characteristics database (http://edcdaac.usgs.gov/glcc/glcc.html);
- FAO digital soil map of the world (http://www.fao.org/ag/agl/agll/prtsoil.htm);
- A daily version of the NOAA 10-day rainfall estimate (RFE) images (http://edcintl.cr.usgs.gov/adds/data/data.html);
- Daily potential evapotranspiration fields derived using Global Data Assimilation System (GDAS) climate fields as input to the Penman-Monteith equation.

The HYDRO1K data provides basin boundaries and stream networks that form the spatial framework of the model. These elements carry identification numbers that embed topological (upstream-downstream connectivity) information in the digits - thus the need for complex linkage tables that add to the computational burden is avoided. Grid cell resolution for HYDRO1K data is one kilometer. The FAO soil map provides characterization of the hydraulic properties of the earth's surface that are required to compute the water balance within a basin. Its original scale is 1:5,000,000, roughly equivalent to a 5-km resolution. The NOAA RFE are calculated on a 0.1-degree latitude/longitude grid, approximately 10-km resolution. They provide the estimates of gross precipitation input to each basin. This product is prepared from METEOSAT thermal infrared images and ground based rainfall stations.

6.5.10 Daily prediction hydrographs

Updated plots of daily-simulated stream flow, for the period January through April, are provided for the important rivers. The model has not been calibrated (nor validated) with observed data, nor have the effects of dams on stream flow timing and magnitude been included. The utility of the hydrograph traces lies in their ability to illustrate trends in river flow magnitude and persistence. This model is still under development and these hydrographs are considered experimental. Model estimated hydrographs for dates in the future are based on quantitative precipitation forecasts (QPF) provided by NOAA.

6.5.11 Rainfall estimates

A technique for estimation of precipitation over Africa was developed to augment the rainfall data available from the relatively sparse observational network of rain gauge stations over this region. The method utilizes Meteosat satellite data, Global Telecommunication System (GTS) rain gauge reports, and microwave data from SSM/I and AMSU for the computation of estimates of accumulated rainfall. Rainfall Estimates (RFE) are produced by NOAA/CPC (Climate Prediction Center) to assist in drought and flood risk-monitoring efforts for the African continent.

6.5.12 Wide-Area Flood Risk Monitoring Model (See appendix 4 for details)

6.6 Earth observation and remote sensing as a tool for developing an early warning system

Remote Sensing technologies have proved to be valuable tools to support effective early warning for disasters. With the advent of remote sensing technologies, monitoring of atmosphere and retrieval of meteorological parameters has become simpler and scientists are using this information in daily weather forecasts. Numerous satellites with broadband electromagnetic wavelengths enable collection and monitoring of data about atmospheric conditions and characteristics of the Earth's surface, leading to processes that may be able to predict natural disasters. Such information can be used to help determine appropriate actions to reduce the disastrous effects of these processes.

6.6.1 Characteristics of remote sensing technologies

Earth observation satellite systems provide a wealth of detailed information at a global level for early warning activities. This information includes two categories of data: first, numerical values of detected geophysical parameters or related measurements, and second, imaging data sensed in various electromagnetic bands. Many different space systems exist, with different characteristics related to:

- Spatial distribution: the size of the area on the terrain that is covered by the instantaneous field of view of a detector
- Spatial resolution: the minimum distance at which two adjacent targets are detected as individually separated
- Temporal resolution: the time taken for a satellite to revisit the same part of the Earth's surface
- Spectral resolution: the number and width of the spectral bands recorded
- Radiometric resolution: the accuracy of the sensor response to the changes of signal to be detected

Data from satellites are collected through a variety of technologies that apply to both "passive" and "active" earth observations. Whatever the wavelength of the electromagnetic radiation, "passive" systems are meant to use natural radiation sources (e.g., sunlight), whereas active systems (e.g., radar) emit and retrieve radio waves reflected from the Earth's surface.

Ultraviolet-to-infrared systems are sensitive to reflectance, which is a measure of molecular resonance of surface materials; the backscatter of microwaves is sensitive to their roughness and dielectric constant. The advantage of active microwave systems (e.g., Synthetic Aperture Radar) is that they can "illuminate" the Earth's surface and detect relief features regardless of night and weather conditions. Passive observation of the Earth is carried out essentially in high frequencies, usually between less than 0.3 microns (UV band, suitable for Ozone and SO_2 detection, e.g.) and 11 microns (thermal far-IR). It includes the Visible (0.3-0.7 micron) and the near-IR bands (0.7-1.2 micron), like those used to forecast the weather, and the mid-IR (4 micron) sub-band that also senses variations in heat levels. Though less common, passive observation is also carried out in the upper microwave bands (between 50 and 90 GHz) for advanced meteorological studies on cloud systems. Image acquisition techniques may be either film-based (analog) or electro-optical (digital). In the first case, optical or near-IR systems capture light reflected from the surface of the Earth with standard camera technology, and drop film canisters into the atmosphere to be retrieved and processed in hard copy form. Similar digital acquisition is used for SAR data that contain the additional information on the phase changes the signals have undergone after leaving the transmitter. Reconstruction of detailed altitude maps is then obtained by "unwrapping" the phase information across the pixels that constitute the entire SAR image.

High Resolution Imaging Satellites

Besides the use of conventional aerial photographs, which often remain the most useful tools in many types of disaster studies, the application of satellite data has increased enormously over the last few decades. After the initial low spatial resolution images of the LANDSAT MSS (60 x 80 m), LANDSAT also offers thematic mapper images with a spatial resolution of 30 m (except for the thermal infrared band) and an excellent spectral resolution with six bands covering the whole visible and the near and middle infrared part of the spectrum, and with one band in the thermal infrared. LANDSAT has a theoretical temporal resolution of eighteen days; however, weather conditions are a serious limiting factor in this respect, as clouds can hamper the visible band acquisition of data from the ground surface during overpasses. Another limitation of the LANDSAT System is the lack of an adequate stereovision. Theoretically, a stereo mate of a TM image can be produced with the help of a good digital terrain model (DTM), but this remains a poor compensation as long as very detailed DTMs are available. The French SPOT satellite is equipped with two sensor systems, each covering adjacent paths of a 60 km width. The sensors have an off-nadir looking capability, offering the possibility for images with good stereoscopic vision. The option for side views results in a higher temporal resolution. SPOT senses the terrain in a wide panchromatic band and in three narrower spectral bands (green, red and infrared). The spatial resolution in the panchromatic mode is 10 m, while the three spectral bands have a spatial resolution of 20 m. The system lacks spectral bands in the middle and far (thermal) infrared.

LANDSAT has the longest record of widely available high-resolution multi-spectral image data series. However, image data in optical bands can be provided by devices carried on board the spacecraft of other countries, such as the Russian Federation (COSMOS, MIR and other missions), Japan (MOS) and India (IRS). Radar satellite images, available from the European ERS, the Japanese JERS and the Canadian Radarsat satellites offer an all-weather capability, as the system penetrates clouds. Theoretically, this type of image can yield detailed information on surface roughness and micro-morphology; however, the applied wavelengths and viewing angle have made its application in mountainous terrain difficult. Early results of research with radar interferometery are promising, indicating that detailed terrain models with an accuracy of around one meter can be created. This offers the possibility of monitoring water movements. Remote sensing data should generally be linked or calibrated with other types of data obtained from mapping, measurement networks or sampling points, to derive the parameters that are useful in the study of flood disasters. The linkage is done in two ways, either via visual interpretation of the image or via digital data merging and integration. GIS are powerful tools that facilitate the combination of the different types of data required for flood disaster management and the presentation of information in a form best understood by managers or administrators. If all of the currently scheduled government and commercial land-viewing satellite systems orbit as planned, in the near future, a minimum of 19 satellites will be in polar orbit providing land data at resolutions from 1 to 30 meters in panchromatic, multi-spectral and radar formats. This will then provide considerable opportunity to acquire data for improved early warning for natural hazards such as floods.

Disasters are often associated with heavy cloud cover. The use of radar data from ERS, JERS and Radarsat permits the imaging of flooded areas through the clouds even when prohibitive airplane flight conditions exist. Multi-temporal radar images map flooded zones almost automatically, when image data from before, during and after the event are merged in a single colored image where data of the imaging dates are displayed in one of the three basic colors (red, green or blue).

Meteorological Satellite Data for Monitoring the Earth

A global meteorological satellite system monitors the Earth's atmosphere, ocean and land surface areas almost in real time from equatorial and polar orbits. Existing geosynchronous satellites include the Geostationary Operational Environmental Satellites (GOES) operated by the United States (at 75 and 135 degrees West), METEOSAT, operated by the European Organization for the Exploitation of Meteorological Satellites at 0 degrees longitude, the Geostationary Meteorological Satellite (GMS) operated by Japan at 140 degrees East, the Geostationary Observation Meteorological Satellite (GOMS) operated by the Russian Federation at 70 degrees East, and the Indian National Satellite (INSAT) operated by India at around 90 degrees East. Their geo-synchronous equatorial position at 35,800 km of altitude allows them to observe the same regions every few minutes. Moreover, their capacity to provide synoptic observations of regional cloud distributions, atmospheric and ocean temperature, relative humidity, wind velocity, distribution of precipitation and other parameters that could be derived from the satellite images have become essential elements in weather forecasting.

Two of the most useful parameters for early warning activities that could be derived from these satellite data are cloud-top temperature and height. Sun-synchronous meteorological satellites in quasi-polar orbit fly at lower altitudes, in a range between 500 and 1,500 km, and can provide a higher spatial resolution than their geo-synchronous counterparts, although with a much longer revisiting time (6 or 12 hours). Such satellites provide global coverage of the Earth twice every 24 hours, and can be used to determine sea surface temperature with a higher accuracy than what could be achieved from the geostationary orbit. Land-surface data obtained by these satellites have been found particularly useful, and inexpensive, for determining green biomass indices. Analysis of this data is used to monitor the encroachment of desert into previously vegetated areas, thereby marking the onset of a slowly developing disaster. The polar-orbiting meteorological satellites currently in use are those operated by the United States (NOAA-N series), by the Russian Federation (Meteor series) and by China (Feng Yung 1 series). Although their spatial resolution is relatively low, the geostationary and polar-orbiting meteorological satellites together provide operational and high frequency coverage of the entire Earth at very low cost. Thus, the use of their data in early warning, disaster prevention and mitigation practices should be easily achievable by most national and regional emergency planning and response services.

6.6.2 Telecommunications technology for early warning

The benefits of interactive real-time telecommunications links between and among meteorologists, geologists, epidemiologists and the host of other professional disciplines within the disaster management community have long been appreciated. Realizing these perceived benefits, though, has been a challenge in many areas of the world. In urban centers of countries with highly developed economies (locations that provide the economic stimulus frequently needed to motivate the development of new technologies), some of these systems are operating. But in remote areas of these countries in general, if such networks are available at all, they are not likely to be widespread. Within three to five years there will be dozens of geostationary (GEO), low earth orbiting (LEO) and medium earth orbiting (MEO) satellite systems covering the entire world. They will consist of from one to as many as 325 satellites per system and will be a part of the Global Mobile Personal Communications by Satellite (GMPCS). These systems will make it possible and affordable to maintain early warning communications regardless of the nature of a disaster, its location, or the terrain of the affected area. This was not possible five years ago. There are essentially three types of communications technologies or systems for early warning:

- The first is the telemetry associated with the relay of information from sensing technologies, usually to or among scientists involved with the specific the phenomenon, e.g., meteorologists, seismologists, etc. The "system" of these technologies is usually dedicated to the particular application and managed by the scientific establishment.
- The second is the system of communication between and among the community of disaster managers. This may mean the national civil defense establishment, the military, the scientific community, selected governmental ministries or agencies, NGOs and others. These systems of telecommunications are also frequently dedicated for this purpose and managed independently of the "public" telecommunications services, although they also rely on national telecommunications infrastructure such as normal telephone lines.
- Third, there are systems and networks used to transmit or broadcast warning messages and information to the public.

Some elements of these networks are managed by "public" broadcasting entities (such as radio or television station broadcasting towers) while others are operated by local or national telecommunications entities or commercial enterprises. The function of technology that has, historically, been referred to as early warning technology could more accurately be considered early *detectio*n. The telecommunication components to these applications consist of the telemetry between the detection device and the scientific institution.

6.6.3 Towards a global system

The World Meteorological Organization (WMO) has developed, by far, the most extensive organization and operational capabilities for Early Warning Systems for Natural Hazards. It may serve as a model for other sectors or, with appropriate consideration and organizational modification, add scope to its own mission. Meteorological services are required for safety of life and property, the protection of the environment, and for the efficiency and economy of a wide range of weather-sensitive activities. The receipt of observational data, analyses and forecasts by National Meteorological Centers is crucial to the provision of these services. The World Weather Watch (WWW) is the international cooperative program that arranges for the gathering and distribution of real time meteorological information on a worldwide basis required by individual members. This information is also used by other programs of WMO as well as by relevant programs of other international organizations.

<u>The overall objectives of the WWW Program are to:</u>

- Maintain an effective worldwide-integrated system for the collection, processing and rapid exchange of meteorological and related environmental data, analyses and forecasts.
- Make available observational data, analyses, forecasts and other products, in both real-time and delayed access, as may be appropriate, in order to meet the needs of all members of WMO programs and of the relevant programs of other international organizations.
- Arrange for the introduction of standard methods and technology that enable members to make best use of the WWW system to ensure an adequate level of services and also to provide for compatibility of systems essential for cooperation with other agencies.
- Provide the basic infrastructure for the Global Climate Observing System (GCOS) and other WMO and international programs for climate monitoring and studying of climate issues.

<u>The WMO operates at global, regional and national levels. It involves the design, implementation and further development of three closely linked and increasingly integrated core elements:</u>

- The Global Observing System (GOS) consists of facilities and arrangements for making observations at stations on land and at sea, and from aircraft, environmental observation satellites and other platforms. The system is designed to provide observational data for use in both operational and research work. The baseline space-based subsystem of GOS comprises two operational near-polar-orbiting satellites and five operational geostationary environmental satellites. Over 1,000 satellite receivers located worldwide within the National Meteorological or the WMO Secretariat had registered Hydro-meteorological Services by 1996.
- The Global Telecommunications System (GTS) is composed of an increasingly automated network of telecommunications facilities for the rapid, reliable collection and distribution of observational data and processed information (currently the GTS is made up of 311 circuits, 262 of which are operational at signal speeds that vary from 50 baud to 64 kbps).

- The Global Data-processing System (GDPS) consists of world, regional or specialized, and National Meteorological Centers to provide processed data, analyses, and forecast products.

The implementation and integration of these three core elements are supported through two additional programs. The first is the **Data Management** (WDM), which addresses standards and practices for the efficient handing and flow of data and products within the WWW system. The other is WWW **System Support Activities** (SSA), which provides guidance, assistance and training related to the planning, development, and operation of WWW.

6.7 World hydrological cycle observing system (WHYCOS)

The World Hydrological Cycle Observing System (WHYCOS) was developed to contribute to the above goal. Composed of regional systems (HYCOSs) implemented by cooperating nations, WHYCOS will complement national efforts to provide the information required for water resource management. Modeled on WMO's World Weather Watch (WWW), and using the same information and telecommunications technology, WHYCOS will provide a vehicle not only for disseminating high quality information, but also for promoting international collaboration. It will build the capacity of national Hydrological Services (NHSs), so that they are ready to face the demands of the 21st century. It will provide a means for the international community to monitor more accurately water resources at the global level, and to understand the global hydrological cycle. The first steps in implementing WHYCOS have been made through regional WHYCOSs in the Mediterranean, Southern Africa, and West-Central Africa. They have been made possible by collaboration between WMO, the World Bank, the European Union, and the Government of France.

6.7.1 The need for WHYCOS

During this century, the pressure on water resources increased dramatically. The world's population has already reached 5.5 billion, and will pass 8 billion within two decades. In 1997, one third of the world's population was estimated to live under water-stress conditions, and it is expected that by 2025 two thirds of the population will do so. Demand for water will only increase, but growing pollution is likely to reduce the available quantity of suitable water. Irrigated agriculture and hydroelectric power generation compete with other uses for limited water within national boundaries. At the same time, maintaining the health of aquatic ecosystems is increasingly accepted as an essential concern. About 300 river basins and numerous aquifers are shared among two or more nations; competition for water among nations could become a potential source of conflict.

Planning and decision-making must achieve new levels of sophistication, reliability, and acceptance. This will demand timely, accurate and comprehensive information about the status of water resources, to complement information about the economic, social, and environmental dimensions of water use. Unfortunately, in many parts of the world the systems for collecting and managing water-related information are inadequate, and often are deteriorating. Particular difficulties include a lack of resources to maintain observing stations, differing procedures for collecting data, variations in quality assurance procedures and standards between different agencies and countries, unreliable telecommunication systems, and outdated systems for information management.

For all these reasons, in 1993 WMO launched WHYCOS. Its objectives are to:

- Strengthen the technical and institutional capacities of hydrological services to capture and process hydrological data, and meet the needs of their end users for information on the status and trend of water resources
- Establish a global network of national hydrological observatories which provide information of a consistent quality, transmitted in real time to national and regional databases, via the Global Telecommunication System (GTS) of WMO
- Promote and facilitate the dissemination and use of water-related information, using modern information technology such as the World Wide Web and CD-ROMs

6.7.2 WHYCOS concept

WHYCOS is a global Programme, modeled on the WMO's World Weather Watch.

It has two components:

- A support component, which strengthens cooperative links among participating countries
- An operational component, which achieves "on the ground" implementation at regional and international river basin levels

6.7.3 WHYCOS data network

WHYCOS is based on a global network of reference stations, which transmit hydrological and meteorological data in near real-time, via satellites, to NHSs and regional centers. These data enable the provision of constantly updated national and regionally distributed databases, of consistently high quality. WHYCOS aims to support, in all parts of the world, the establishment and enhancement of information systems that can supply reliable water-related data to resource planners, decision makers, scientists and the general public.

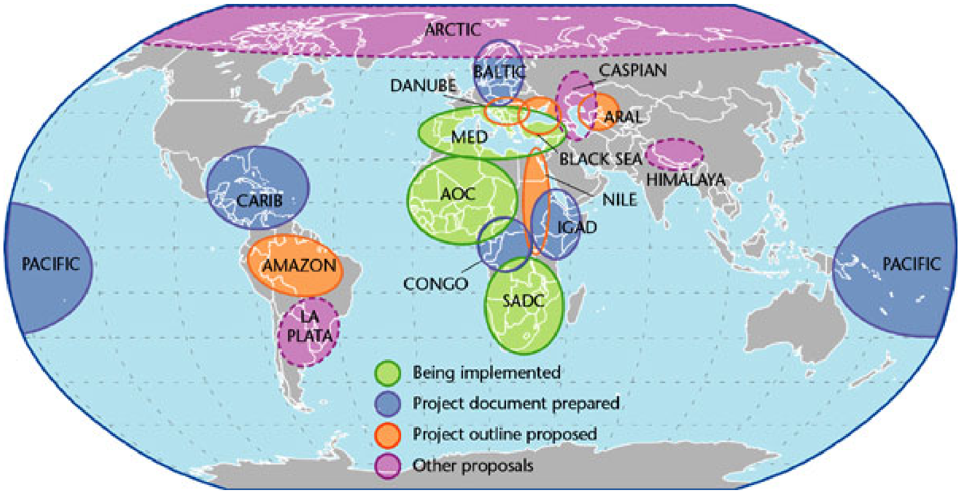


Fig. 6.7-1 WHYCOS regional components around the world (Source: WHYCOS, 2001)

WHYCOS does not replace existing hydrological observing programmes, but supplements them. An important product of WHYCOS is regional datasets that are of consistent quality and can be used in preparing products for water resources assessment and management. In its initial phase, WHYCOS has focused on establishing components in international river basins, in the catchment areas of enclosed seas, and in regions of Africa that are poorly served by hydrological information

By providing a framework of common guidelines and standards, WHYCOS enables the use of information from the regional HYCOSs for larger scale applications, such as research into the global hydrological cycle. Hence, WHYCOS can make an important contribution to the work of other WMO and international scientific programmes which require water-related information.

6.7.4 Working of WHYCOS

WHYCOS consists of a number of regional components, each of which is independently implemented and responsive to local needs. Each component is launched when the countries concerned have expressed their collective desire for such a development and their commitment to making it a success.

Implementation at a regional scale enables each HYCOS to establish institutional and financial arrangements that are appropriate to the region. It also allows each HYCOS to select activities and procedures and design products which are specific to the hydrological characteristics of the region and also meet the particular needs of the region, the participating countries and their hydrological services, and the end users.

Key steps in establishing a regional WHYCOS include:

- **Reaching agreement among participating countries to proceed with establishing a HYCOS.** This is an essential first step, to ensure that there is joint commitment to the concept, and that the system will be maintained into the future.
- **Defining the needs that are to be met**. In general, these include the information required to underpin sustainable economic and social development in the participating countries, specific needs for capacity building in their hydrological services, and the needs of the international community for hydrological data to

support global water resources assessment and hydrological/environmental science. An Information Infrastructure Directory provides contact information on the HYCOS participants, collaborators and end users.

- **Installing a real-time data collection and transmission system**. This system consists of observing stations equipped with Data Collection Platforms (DCPs), transmitting data via satellites, the GTS and the Internet, and includes national and regional data receiving centers. The DCPs incorporate multiple sensors to capture up to 16 variables, which describe the state of the local water resource and weather conditions. The observing stations are nationally and regionally important benchmark sites, most of which already exist, but require upgrading.
- **Upgrading national data processing and archiving systems**. Implementation of a HYCOS provides a vehicle for installing new equipment for archiving and retrieving data, introducing refined data processing and quality assurance procedures, and providing appropriate staff training. Existing facilities are used as a starting point, but are strengthened and extended as necessary.
- **Establishing distributed regional databases**. These are designed to provide data of defined and consistent quality, which are regularly updated and available to users in a timely manner. The existence of distributed regional databases provides support for individual countries, and provides opportunities for more efficient handling of information about shared water bodies.
- **Establishing a regional telecommunication network**. This is designed to exchange messages, verify data and information via e-mail and electronic file, and document transmission. The network encourages collaboration between governments, hydrological services, and other operational or research organizations.
- **Preparing and disseminating hydrological information of national and regional interest**. A wide range of information products, which meet specific user needs, can be prepared from the data provided by the observing system. This includes forecasts, hydrological statistics, information on trends on the state of the water resource, or "yearbooks" in electronic format. Products are designed to meet specific needs of users and are widely disseminated via the regional telecommunication network as well as other more traditional methods.
- **Staff training.** Training in the use of the newly introduced technology is essential, but the opportunity can also be taken to provide refresher training in more conventional hydrological skills, as well as in non-technical areas such as administration, public relations, marketing and customer service.
- **Performance monitoring and follow-up**. Careful monitoring of performance against defined objectives will be maintained, to avoid the difficulties that in the past have been so common in capacity-building programmes. This will provide the ability to identify impediments to successful implementation and their removal, thus assuring long-term sustainability.

6.7.5 WHYCOS, other observing systems and data exchange

The international community has established several global observing systems and scientific programmes, the aim of which are to monitor the state of the global environment, detect changes, and provide the scientific knowledge required to develop appropriate response strategies. These systems include the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS), the Global Oceanic Observing System (GOOS), and the Global Environment Monitoring System (GEMS). At present there is no common mechanism for the exchange of water-related observations. Hence, it is not possible to integrate and make efficient use of all the observations that are presently made. WHYCOS will contribute to a solution by providing a single, easily accessed source of information on selected hydrological information of global significance. A major contribution of WHYCOS will be to provide a means of incorporating information about the global water cycle into efforts to understand the global environment.

A key element for promoting data exchange and scientific cooperation is the establishment, using Internet and other modern data transmission technologies, of a "global hydrological information system." It will provide a medium for easy, fast dissemination and exchange of water-related data and information, which has become a prerequisite for efficient and cost-effective operational hydrology. The "global hydrological information system" will be coordinated with existing information networks and databases at national, regional and global levels. In addition to meeting the needs of national and regional users, the global system will enable the exchange of information with databases maintained under the family of Global Observing Systems (GOSs).

Participating Hydrological Services will establish sites on the World Wide Web to enable easy access to selected information. Raw data will be available in near-real time, although the service responsible for each monitoring station will subsequently carry out data quality assurance, according to WHYCOS criteria of data standards and timeliness. Derived products, such as maps of specific runoff, may be subject to cost recovery, to generate revenue for the hydrological services.

To ensure that WHYCOS data and products meet the requirements of the end users, the global system and sites on the World Wide Web will be used for discussing results, obtaining feedback, expressing needs, and sharing ideas and views. Electronic communication will be supplemented by face-to-face meetings for purposes such as fine-tuning programme outputs to meet the precise needs of end users.

The worldwide WHYCOS network will initially consist of about 1000 benchmark stations sited on major or critical rivers, lakes and reservoirs. The participating countries, from among existing stations that might be readily upgraded to a common WHYCOS technical standard, will propose stations. Criteria for selection of stations will depend on the following criteria**:**

- Availability of a long historical record
- A stable water level-discharge relationship
- Regional significance

Stations will normally capture a minimum set of observations**:**

- Water level/flow
- Precipitation
- Temperature
- Humidity

Other variables required to estimate potential evapotranspiration and to describe the physical and chemical characteristics of the water would also be measured at many locations. The stations will be equipped with Data Collection Platforms, which transmit via meteorological satellites (METEOSAT, GOES, etc.) and the Global Telecommunication System of WMO, to Data Receiving Stations located at regional and national centers.

6.7.6 Regional databases

The WHYCOS regional databases will be distributed databases, with operational centers at national and regional levels (Regional Pilot Centers) linked using flexible, easy-to-use communication networks. The databases will be fed in real time by the stations connected via satellite or other data transmission networks and at regular intervals by hydrological services with data from observing stations not linked to the transmission networks. Selected data will also be conveyed to the Global Runoff Data Center, adding to its global archive.

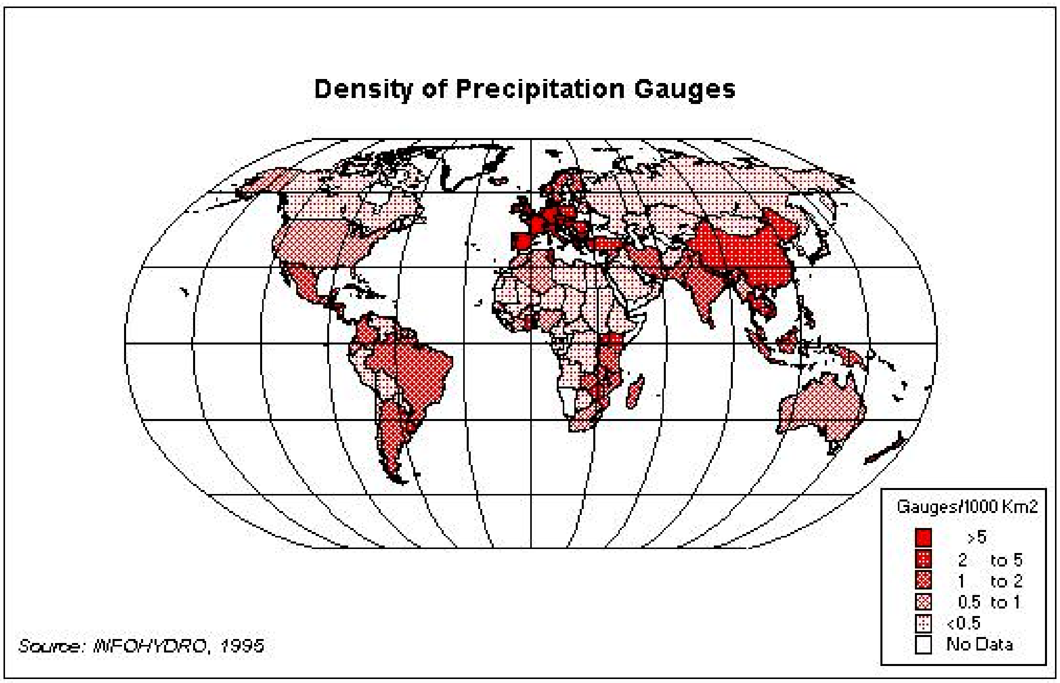


Fig. 6.7-2 Global Precipitation Gauges (Source: WHYCOS, 2001)

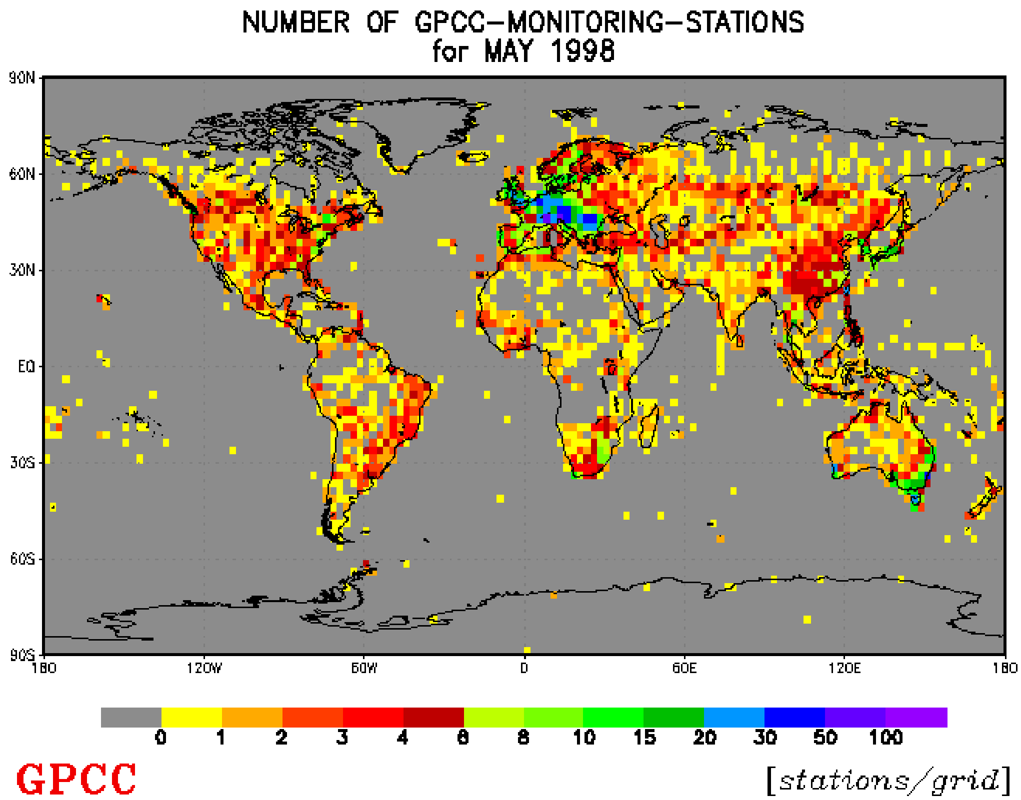


Fig. 6.7-3 shows about 200,000 routinely operating recording precipitation gauges around the world during the last 4 decades (Source: WHYCOS, 2001)

The databases will support:

- Monitoring operation of the regional network of benchmark stations
- Disseminating data to end users at national, regional and global levels
- Preparing products for regional water resources assessment and drought
- Management, flood forecasting and reservoir operation

Fig.6.7-2 shows the density of precipitation gauges throughout the globe and Fig. 6.7-3 shows about 200,000 routinely operating recording precipitation gauges around the world during the last 4 decades. The density of gauges is quite variable, and it relates quite well to the population density.

6.8 The Global Climate Observing System

Another major component of WMO's climate agenda is the Global Climate Observing System (GCOS). GCOS was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is cosponsored by the WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS is intended to provide the comprehensive observations required for monitoring the climate system, for detecting and attributing climate change, for assessing the impacts of climate variability and change, and for supporting research toward improved understanding, modeling and prediction of the climate system.

6.9 Global Atmospheric Watch (GAW)

Set up in 1989, the WMO's Global Atmospheric Watch integrates the many individual monitoring and research activities involving the measurement of atmospheric composition, and serves as an early warning system to detect further changes in atmospheric concentrations of greenhouse gases, changes in the ozone layer and in the long-range transport of pollutants. As part of this program, WMO issues regular bulletins on the state of the ozone layer over the Antarctic.

The AFWS web site is a cooperative effort managed by the IFLOWS Program of the National Weather Service. Information and products available at this site are from many sources, and in many cases collected from or through systems beyond the control of the NWS or any individual cooperator. The availability and accuracy of weather data via Internet and this site therefore cannot be assured. The rain gage data/Web Site Trouble Page of this site lists contact points for some of the specific systems contributing information to the site.

6.10 Foreign assistant in Central America as an example

6.10.1 Early Warning Preparedness

Recognizing that Central America has limited severe weather warning and forecast services, NOAA has helped to create the infrastructure necessary to improve forecasts and early storm warnings through disaster preparedness and response.

<u>Key elements include:</u>

- Replaced damaged and expanded automatic meteorological and hydrological stations.
- Reestablished upper air station in Honduras critical for hurricane forecasting.
- Provided automated precipitation gauges for real-time data.
- Improved capabilities to receive and interpret satellite imagery for the region.
- Established a regional, seasonal climate prediction system.
- Provided a satellite ground station that brings high-resolution digital imagery from NOAA's Geostationary Operational Environmental Satellites (GOES).
- In cooperation with USGS, rebuilt tools to measure water levels, tides and geodetic positioning networks.
- NOAA and USGS provided technology for state-of-the-art river and flood forecast systems.

6.10.2 Coastal Assistance as an example

NOAA also advised on regional watershed management and assisted in building more sustainable and resilient coastal communities. NOAA's environmental scientists are improving coastal management in the region to lessen the impacts of future weather disasters and improve response capabilities.

This includes:

- Improving capabilities along coasts to cope with impacts of hurricanes.
- Installing tide gauge networks.
- Rebuilding the aquaculture shrimp industry and providing more information on water circulation and contaminant levels in the Gulf of Fonseca - an important bay on the Pacific coast.

Traditionally, environmental information such as that required for hydrological applications has been provided by optical remote sensing; however, it was often hampered by time-of-day or weather constraints. In addition, the restricted penetration of optical wavelengths into a volume, such as a vegetative canopy or soil, limited the amount of information on hydrological conditions that could be derived from an image. Because SAR is an active microwave system, it has day and night data imaging capabilities, and the low frequencies (relative to optical systems) allow for data acquisition in fog and light rain. It is particularly well suited to hydrological applications due to the sensitivity of microwave energy to the presence of water. Radar also provides greater penetration into vegetation, soil or snowpack, thus allowing surface and subsurface information to be acquired.

Field studies for hydrological applications are able to provide hydrological information at discrete points; however, these data are limited because the phenomenon being measured (e.g., soil moisture, flood extent) is highly variable over space and time, and there are difficulties in timing field data collections with dynamic events such as floods. Radar remote sensing can provide the near real time and synoptic view necessary to map hydrological features on a regional scale, and may also provide validations or supporting information for field data collection.

When radar data is acquired for quantitative hydrological study or any other application, it is important that data is calibrated as it allows image brightness values to be more directly related to target backscatter. When radar data is acquired over longer periods for the purpose of monitoring change for hydrological applications, it is again important that data is calibrated. Image calibration for change detection ensures that any change in the image is a result of a change in the target and not from a change in the sensor.

The hydrological applications of radar remote sensing that are of importance to water resources management include watershed modeling, flood mapping and fresh water ice mapping. The use of radar for watershed modeling involves many activities including soil moisture estimation, mapping of land cover, and determining wetland and snowpack conditions. Information acquired from these activities is input into models to predict the hydrological characteristics of a watershed. This in turn provides an estimate of the availability of free water for such activities as hydroelectricity production and crop irrigation.

The measurement of soil moisture aids in the prediction of crop yield, plant stress and watershed runoff (Brown et al. 1993). The measurement of soil moisture by C-band radar is possible due to changes in the dielectric properties of materials produced by changes in water content.

Land cover information provided by radar is an important input to watershed modeling as land cover determines in part the amount of free water available for runoff.

Stream flow predictions can thus be made to determine water availability for other uses. Land cover information using radar is valuable because of the differences in radar response to variations in geometric structure and moisture content associated with different land cover types.

Wetland condition determination is imperative to watershed modeling as wetlands provide vital clues to the state and availability of hydrological resources within a watershed. Mapping wetland boundaries is possible using radar because of its sensitivity to changes in the dielectric constant at the wetland boundary. In many areas of the world, the majority of fresh water available for consumption and irrigation results from snowpack runoff. Snow wetness, snow-water equivalent and aerial extent of the snow cover are the most important parameters in predicting total runoff. Mapping the extent of wet snow is possible using SAR data (Rott et al. 1988); wet snow produces a low radar return in contrast to dry snow that is essentially transparent at C-band.

Fresh water ice mapping using radar is an effective tool for the evaluation of ice conditions in rivers and lakes for flood prediction. The buildup of ice may prevent the normal flow of water that produces flooded conditions. Information provided from fresh water ice mapping helps in the implementation of preventative measures and evacuation procedures. Radar is capable of fresh water ice mapping due to volume and surface scattering from ice that has significant contrasts with the specular reflection from open water.

7 Study areas and database development

Most watersheds of the major rivers in the world are important to all living beings because they contain some of the most productive ecosystems. They provide valuable resources and contribute significantly to a country’s economy by providing employment, economic resources, and waterways for navigation and transportation of goods. Also the environment of these watersheds supports pristine habitats that include human life, wildlife and vegetation with high biological diversity.

Floods remain one of the most frequent and devastating natural hazards worldwide. In recent years the frequency of abnormal floods in Bangladesh, China and India has increased substantially, causing serious damage to lives and property. Unusual or above normal surface-water flow that inundates otherwise high ground is called a flood. Riverine floods occur when the amount of water flowing in a drainage basin or watershed (the area that collects and directs the surface water into the streams) exceeds the carrying capacity of rivers that drain the area. Flooding can occur due to river overflow or surface runoff. Flooding propensity in an area can vary greatly with a change in the water carrying capacity of a drainage basin or with a change in land elevation with respect to the basin level (the depth to which a river can cause erosion) of rivers – the ocean.

7.1 Survey of study areas

7.1.1 Selection of the study areas

In the recent past, numerous flood incidences took place throughout the globe. Such incidences are very common and frequent in the Asian region, due to unpredictable weather events. It is believed that the frequency of such incidences is increasing due to global climatic change. Most of the Asian countries (including India, Indonesia, China, Bangladesh, Pakistan, Vietnam, and Malaysia), where nearly half of the world's population lives, are prone to unpredictable weather events and natural disasters. These events are a major threat to life and property. Due to high population density along the rivers, especially in Asian countries such as Bangladesh, China and India, floods create huge loss of lives and property every year. For example, a consequence of the flooding occurring in Asia in 1991 was a final death toll surpassing 139,000 in Bangladesh alone. The Yangtze and Ganges/Brahmaputra River basins are the largest basins in Asia and the most heavily populated. Both are highly susceptible to large scale, disastrous flooding.

7.1.2 Basic information of the study areas

Ganges/Brahmaputra basin (India and Bangladesh)

The Ganges and Brahmaputra are two of the world's greatest rivers. The Ganges' wide valley stretches across northern India and Bangladesh from the Himalayas to the Bay of Bengal. It is one of the most fertile of all agricultural regions. Its rice and other crops feed most of India and Bangladesh. The Padma River crosses the meeting point of the River Ganges and Brahmaputra. The river is also an important trade artery.

Millions of Hindus venerate the Ganges as a "life-giving river" because their crops depend on its waters. To them the Ganges is sacred. They call it Gangamai, meaning "Mother Ganges." They believe that bathing in its waters washes away sin. To die on its banks assures eternal peace to the soul.

The Ganges is about 1,557 miles (2,506 kilometers) long. The Ganges Valley, or basin, is 200 to 400 miles (322 to 644 kilometers) wide. The total drainage basin covers an area of about 376,800 square miles (975,900 square kilometers). The river starts in an ice cave on the southern slopes of the Himalayas, some 10,300 feet (3,140 meters) above sea level.

Fig. 7.1-1 The Maha Kumbh Mela (great urn fair) is the greatest festival in the Hindu religious calendar -- a holy gathering at the confluence of India's Ganges and Yamuna rivers. Lasting 42 days, it is held every 12 years and brings together the faithful from across all India -- businessmen, priests, farmers, and widows. It is rotated among four sites where a God on his way to heaven is believed to have accidentally spilled an urn containing the nectar of eternal life (Source: Robert Nickelsberg/Liaison for TIME)

The headwater of the Ganges in the Himalayas is called Bhagirathi. The Ganges breaks out of the foothills at Hardwar and is joined by many small tributaries. Midway in its course, near Allahabad, it is joined by its chief tributary, the Yamuna (Jumna) River. The Hooghly River, an old channel of the Ganges, joins it at the delta.

Between the Ganges and the Yamuna is a doab, meaning "land between rivers." It is irrigated by two large canal systems supplied by the snow-fed Ganges. Rainfall in the valley ranges from 80 inches (203 centimeters) a year at the delta to about 25 inches (63 centimeters) in the Upper Ganges. The water supply of the Ganges system is dependent partly on the rains brought by the monsoon winds from July to October. Melting Himalayan snows in the hot season, from April to June, also contribute to the supply.

The Ganges Valley is one of the most thickly populated agricultural regions in the world. Within the basin's 750,000 square kilometers (km^2) live 400 million people. Most of the original natural vegetation and wild animals have disappeared, and the land is now heavily cultivated to meet the needs of a rapidly growing population.

Use of water for irrigation, either when the Ganges floods or by means of gravity canals, has been common since early times. Irrigation has increased the production of such food and cash crops as wheat, sugarcane, cotton, and oilseeds in the states of Uttar Pradesh and Bihar. River traffic is insignificant above the Middle Ganges basin around Allahabad, where railways serve the region, but the rural people of West Bengal and Bangladesh continue to rely on the waterway to transport their agricultural products.

The Yamuna River flows to the west and south of the Ganges and joins almost halfway down its course. The Yamaha receives a number of rivers of central India. To the north of the Ganges, the large tributaries are Ramganga, Gomati, Ghagra, Gandak, Saptkosi, and the Mahananda. Beyond Mahananda the river enters its own delta, formed by its distributaries, and then merges into the combined delta of the Ganges, Brahmaputra, and Meghna Rivers.

The Ganges River and its tributaries and distributaries flow through three countries: India, Nepal, and Bangladesh. The Ganges basin river system remains the main source of freshwater for half the population of India and Bangladesh and nearly the entire population of Nepal. The importance of the Ganges can hardly be exaggerated, particularly in its lower stretch, where it is the only river from which freshwater supplies are obtained for the distributaries (small rivers that distribute waters through a flood plain during peak flows). Freshwater is now a highly prized commodity. As the development of South Asia picks up momentum and populations increase, the Ganges River system rapidly increases its importance.

The Lower Ganges basin contains both an active delta and a moribund delta, both of which are affected by enormous flood flows in the Ganges, relentless tidal pressures from the sea, and occasional severe cyclonic storms capable of disrupting environmental systems. The balance of environmental factors is extremely delicate and complicated, so small changes in one factor affect all the others. The major environmental issues which are associated with population factors include: increasing demands on natural resources from development activities; the inward penetration of higher salinity levels; the spread of waterborne diseases due to the extensive embankment of former bodies of water; water and soil pollution; decline in fisheries due to human interventions; and the excessive felling of the Sunderbans forest.

Bangladesh, being the downstream and deltaic portion of a huge watershed, is naturally vulnerable to the water quality and quantity that flows into it from upstream. All major rivers flowing through Bangladesh have their origins outside its borders; therefore any interventions in the upper riparian regions have a significant impact on Bangladesh. Through its complex network of river systems, Bangladesh drains roughly 1.76 million km^2 of catchment areas of the Ganges, Brahmaputra, and Meghna Rivers, even though only 7 percent of the water resources and population pressures in the Ganges River basin lie in Bangladesh. This physical characteristic severely limits the degree of control and management of the inflow water in the monsoon and dry season. The extreme variations of temporal and spatial occurrence of rainfall are a major constraint to the development of agriculture, which dominates the economy.

The Brahmaputra River is an important waterway of southern Asia. This river rises on the northern slopes of the Himalayas in Tibet of China. After flowing 1,680 miles (2,704 kilometers) through India and Bangladesh, this river joins the Ganges River and shares the Ganges Delta. The northern part of the river has many names, sometimes called Yarlung Zangbo in Tibet of China. It flows eastward and disappears into the Bay of Bengal forming a vast delta. At the delta the southward-flowing Brahmaputra River joins the Ganges. Their combined delta is the largest in the world. The delta begins more than 200 miles (322 kilometers) from the Bay of Bengal and lies mostly in Bangladesh. It is largely a tangled swampland.

The Brahmaputra basin is a major river system, covering a drainage area of 580,000 km^2, of which 50.5 % lies in China, 33.6% in India, 8.1% in Bangladesh and 7.8% in Bhutan. This basin represents a unique hydroclimatological and geo-biophysical setting characterized by a dominant monsoon rainfall regime, a relatively fragile geologic base, highly active seism city and an immensely rich biodiversity. The hydrologic regime of the Brahmaputra responds to the seasonal rhythm of the monsoon and freeze-thaw cycle of Himalayan snow in the backdrop of a unique geo-environmental framework. The river carries a mean annual flood discharge of 48,160 m^3/sec at Pandu (India) where the highest recorded flood was 72,748 m^3/sec (1963) with a recurrence interval of 100 years. The flow hydrograph of the river is marked by exceedingly high variability of discharge during the monsoon high flow season from June through September. The average annual rainfall in the basin is 230 cm with a marked variability in distribution over the catchment. Rainfall in the lower Himalayan region amounts to more than 500 cm per year, with higher elevations getting progressively lesser amounts. The excessive rainfall intensity occasionally causes flash floods, landslides, debris flow and erosion. Patterns of correlation of concurrent flows in different tributary rivers and among various stations on the mainstream have been examined. Few extreme climatic events recorded so far in the Eastern Himalayan are analyzed and their hydrological consequences mainly in regard to water-induced mountain disasters like floods and landslides are discussed. The changing land use (mainly deforestation) and development as well as population pressures in the region and their hydrological implications are also highlighted with the help of selected illustrations. The impact of Himalayan neotectonics on the hydrologic regime of the Brahmaputra especially with regards to the 1897 and 1950 earthquakes (both of Richter magnitude 8.7) is discussed based on the analysis of observed hydrological data. The pattern of accumulation and depletion of snow and glacial cover in the Tista and Kameng sub-basins of the Brahmaputra is delineated using satellite remote sensing techniques and melt water runoff is estimated. Lack of sufficient and reliable hydrometeorological data and information shows the need for greater regional cooperation and international assistance. Strengthening of the hydro-meteorological monitoring network in the Eastern Himalayas especially with respect to the upper catchment of the Brahmaputra River and development of scientific and manpower base in the area of hydrological and climatic research are considered to be of prime importance for sustainable development of the immense water resources potential, preservation of its unique ecological wealth and for management of natural hazards.

Although still a point of controversy, one of the causes of increased flooding in Bangladesh can be traced from Nepal and India (Assam), where the majority of the rivers originate. Massive deforestation of the mountainsides has significantly reduced the Himalayan's capacity to absorb the monsoon rains, and has greatly increased the amount of eroded soil that is carried by floodwaters.

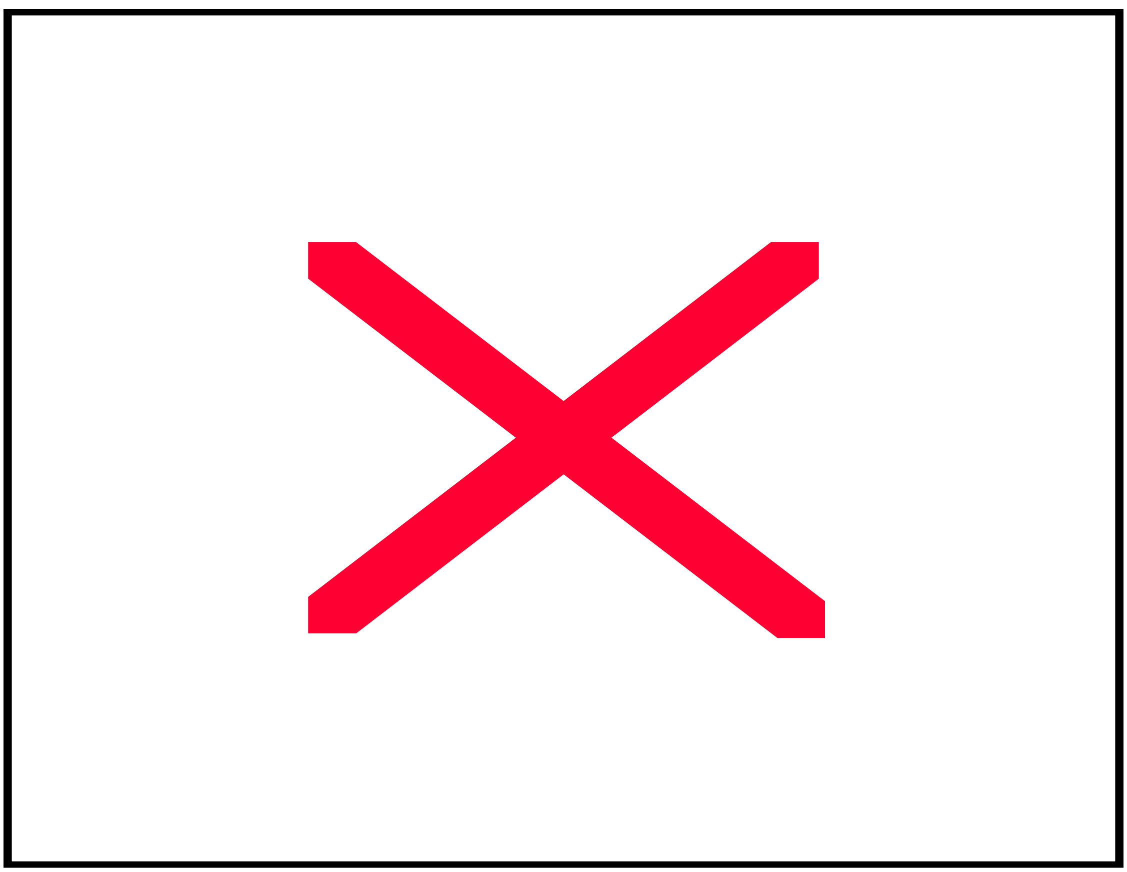


Fig. 7.1-2 Map of the Ganges/Brahmaputra River basin

The physical geography of Bangladesh makes the country and its population extremely vulnerable to disastrous flooding. Bangladesh has more than 80% of its land in the floodplain of the Ganges, Brahamputra and other rivers. With an area of only 144,000 km^2 and a population of 118 million, about 832 persons per km^2, it is one of the most densely populated countries in the world (UNDP, 1995). In this semi-tropical, predominantly rural country, roughly 48 percent of the rural population and 44 percent of the urban population live below the poverty line (BBS, 1995). Per capita gross national product in 1991 was US$ 220. Households spend 59 percent of their income on food, and 60 percent of children under 5 years of age are malnourished.

The Lower Ganges basin comes under the jurisdiction of the greater districts of Kushtia, Jessore, Faridpur, Khulna, Barisal, and Patuakhali. It comprises an area of approximately 40,450 km^2, or 27 percent of Bangladesh's total area. It is bordered by India to the west, by the Ganges (Padma) and Lower Meghna rivers to the north and east, and by the Bay of Bengal to the south. Sixty-two percent of the region is cultivated. Roughly 10 percent, or 4,000 km^2, is covered with a coastal mangrove forest known as the Sunderbans. Surface water areas, including rivers and natural land depressions known as beels, cover approximately 13 percent of the country. The northern part of the area is comparatively high to medium-high land with a rolling topography. Further south, the topography starts off as gently sloping but soon becomes very flat. This southern part has a large number of beels and low-lying areas. In addition, the coastal areas, which include the Sunderbans, are criss-crossed by a number of tidal rivers and creeks.

The area has a typical monsoon climate with a warm and dry season from March to May, followed by a rainy season from June to October and winter period from November to February. The mean annual rainfall is 2,000 millimeters (mm), of which approximately 70 percent occurs during the monsoon season. Rainfall generally varies from northwest to southeast, increasing from a mean annual rainfall of 1,500 mm in the northeast to 2,900 mm in the southeastern corner. Potential evapotranspiration rates are approximately 1,500 mm and exceed rainfall rates from November to May. The relative humidity is high, varying from 70 percent in March to 89 percent in July. The area experiences moderate to high duration of sunshine hours, and durations in excess of 8.5 hours outside the monsoon season. The mean annual temperature is 26^o Celsius (C) with peaks of over 30^o C in May. Winter temperatures can fall to 10^o C in January.

The southern region of the area and in particular the southeastern coastline is vulnerable to cyclones during the monsoon season. Storm surges can cause dramatic increases in the water level of up to 4 meters above tide and seasonal levels. The southwest coastline is protected to some extent by the dampening effects of the Sunderbans, although surges do progress up the major rivers.

The coastal zone consists of the extensive flat, coastal and deltaic land of the Ganges Delta, which is crossed by large tidal rivers discharging into the Bay of Bengal. The Lower Ganges basin coastal zone is in a state of transition. It is changing from an actively developing delta of the Ganges to a semi-moribund delta partially sustained by local rivers.

The coastal area is subjected to coastal processes, which include tides causing periodic variations in water levels and currents, consequential saline intrusion, wave attack on the coastal fringe, surges and extreme wave attacks due to cyclones, and possible long-term sea-level rise due to global warming.

As a consequence of the flat topography, coastal processes have a major impact on the freshwater resources of the area. Tidal propagation into the delta system carries saline water inland, which mixes with the fresh water to create different levels of salinity in the river system, depending on the upland freshwater discharges.

The western half of the Ganges delta contains the Sunderbans, which is the largest single block of natural mangrove forest in the world. It covers 5,892 km^2, and contains a continuing, dynamic, and changing mosaic of plant communities. The Sunderbans house many species of flora and fauna, and part of it is being considered as a World Heritage Site. At present, the Sunderbans are under considerable threat, which may be attributed to the reduction in the freshwater flushing action caused by upstream extraction at the Farakka barrage, increasing shrimp cultivation, over-exploitation of wood resources, increased agriculture, and increased silt deposits.

Yangtze basin (China)

The Yangtze River or Chang Jiang, the longest river of Asia and the third longest of the world, in China, is about 6300 km (about 3,937 mi) in length. It rises in the Kunlun Mountains in the southwestern section of Qinghai Province, and flows generally south through Sichuan Province into Yunnan Province, where, in the vicinity of Huize, it bends sharply to the northeast. Then, it flows generally northeast and east across central China through Sichuan, Hubei, Anhui, and Jiangsu Provinces to its mouth in the East China Sea, about 23 km (about 14 mi) north of Shanghai.

The headwaters of the Yangtze start at an elevation of about 4900 m (about 16,000 ft). In its descent to sea level, the river falls to an altitude of 305 m (1000 ft) at Yibin, Sichuan Province, the head of navigation for riverboats, and to 192 m (630 ft) at Chongqing. Between Chongqing and Yichang (I-ch'ang), at an altitude of 40 m (130 ft) and a distance of about 320 km (about 200 mi), it passes through the spectacular Yangtze Gorges, which are noted for their natural beauty but are dangerous to shipping. Yichang, 1600 km (1000 mi) from the sea, is the head of navigation for river steamers; ocean vessels may navigate the river to Hankou (Hankow), a distance of almost 1000 km (almost 600 mi) from the sea. For about 320 km (about 200 mi) inland from its mouth, the river is virtually at sea level.

More than 1,683,500 sq km (650,000 sq mi) of territory is drained by the Yangtze and its branches. The principal tributaries are the Han, Yalong, Jialing, Min, and Tuo He (T'o Ho), on the north; on the south, the Wu; at Zhenjiang, the Grand Canal links the Yangtze to the Huang He (Huang Ho). During periods of heavy rains, Lakes Dongting and Poyang receive some of the overflow of the Yangtze. Despite these outlets, floods caused by the river occasionally have caused great destruction of life and property. In the 20th century, devastating floods occurred in 1905, 1980, and 1981.

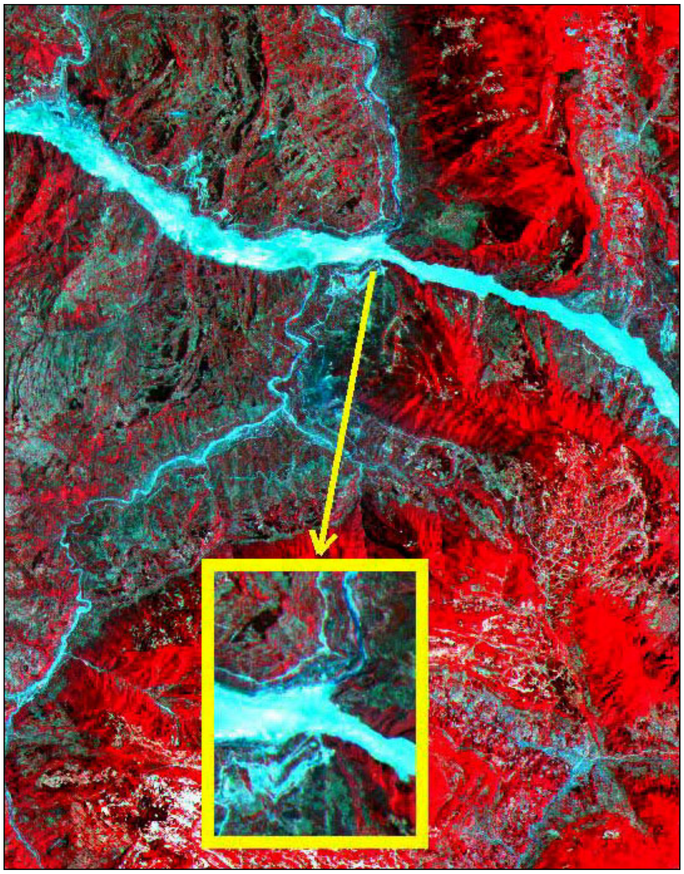


Fig. 7.1-3 Image of Three Gorges of Yangtze river in China (Source: RSI, 2001)

With numerous tributaries and feeders, the Yangtze River provides a great transportation network through the heart of some of the most densely populated and economically important areas in China. Among the principal cities on the Yangtze, in addition to those cited in the foregoing, are Wuchang, Nanjing, Hanyang, and Anqing (An-ch'ing). Jiangsu Province, largely a deltaic plain consisting of silt deposited by the Yangtze river (more than 170 million cu m/6 billion cu ft annually), is one of the chief rice-growing areas of China.

While the entire river (jiang) is known as the Yangtze, the Chinese apply that designation only to the last 480 or 645 km (300 or 400 mi) of its course, the portion traversing the region identified with the Yang kingdom (which flourished about 10th century BC).

From, its upper reaches to Yibin, the river is known as Jinsha (Chin-sha), or “Golden Sand,” and various other names are applied in the provinces it traverses. The official name for the entire river is Chang Jiang, or “Long River.” The Yangtze River basin is an important agricultural and industrial production base to China’s economy. It contains about 1/4 of the farmland of China, which supports over 358 million people, supplies 36.3% of the total crops, 23.5% of the total cotton and 33% of the total vegetable oil to the country, and contributes 49.5% of total Chinese GDP. The Yangtze River is a flooding river. Historically, there were 214 floods during the Han Dynasty (185 B.C.) to the Qing Dynasty (1911 A.C). There were 14 big floods from 1921-2000.

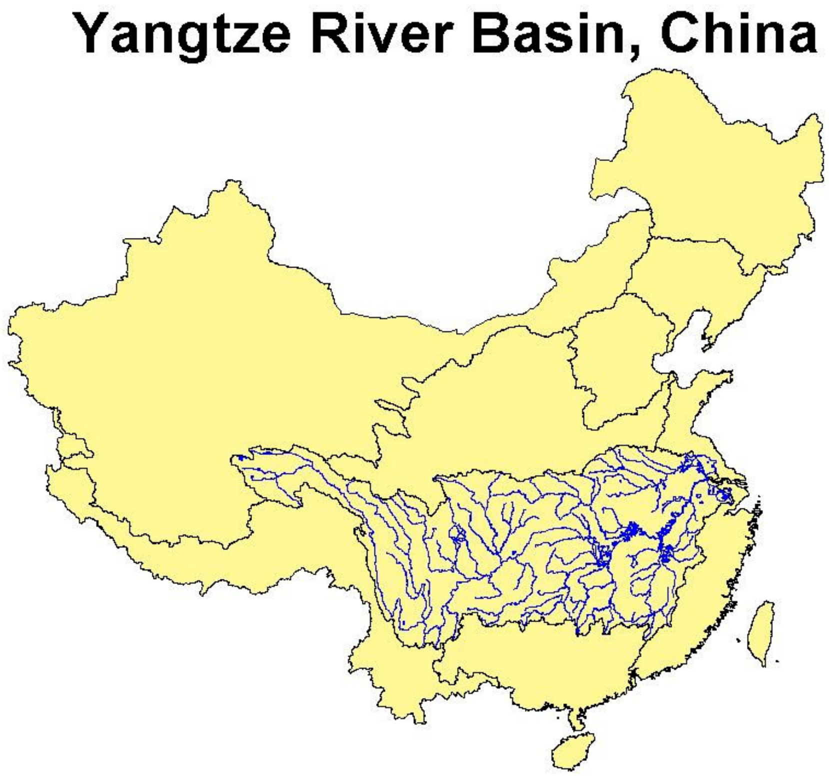


Fig. 7.1-4 The map of the Yangtze River basin, China

7.2 Database development

Several data sets including information available on the Internet have been obtained. GIS data sets have been compiled for the Ganges River basin covering a part of India and Bangladesh, and for the Yangtze River basin in China.

7.2.1 UNEP/GRID database

In an information-based society, both spatial and non-spatial data and information are critical to decision making. This section describes the efforts of UNEP/GRID in developing georeferenced database concerning flood risk monitoring and early warning.

In general, database efforts followed two tracks. One was the compilation of existing digital data for the two river basins. The other was the creation, often involving previously uncompiled data, of very specific data and analysis for the floodplains.

7.2.2 The spatial dimension of information

Many definitions of GIS have been written (Maguire, 1991). Most definitions fall into one of three overlapping categories: 1) map, 2) database, and 3) spatial analysis. Because of the spatial extent, complexity, and potential variety of uses, the UNEP/GRID GIS fits into each of the defining categories. First, it is a method of digitally storing geographic data and producing useful map products from those data. Second, it is a large database and database management system that contains both spatial and non-spatial data of value to management decision makers and scientific analysts alike. Third, it is designed to enable analysis. The analysis conducted has already provided valuable information for policy and management decision-making.

Two basic spatial data structures are used in a GIS database: vector and raster. A vector structure stores data or features as points, lines, or polygons that are defined by a set of Cartesian coordinates. Each feature in a vector layer can have many attributes associated with it – a vegetation layer may have attributes for dominant species, crown height, canopy cover, and so on. A raster structure stores data as a regular array of cells, such as in satellite image data, or in generalized data that could be obtained by laying a grid over the landscape. Typically, single theme data in a single raster cell, or pixel, are given a single value.

In this report, the term 'coverage' refers to a raster or vector-based GIS data set that corresponds to a single theme, or layer. It is the principal storage unit for the UNEP/GRID database. Spatial data can be tied to a location; geospatial data can be tied to a location on, in, or above the Earth.

Relational databases, such as spreadsheets or time-series, often can be tied to a point, line, or an area, and thus become attributes of the GIS coverage. Time-series data are important because they provide an opportunity to relate changes in one phenomenon to changes in another, offering insights to causal relationships, trends, and event frequency that could not be identified or interpreted any other way.

7.2.3 Development of digital data

Since the inception of UNEP/GRID in 1985, efforts have been made to develop a list of data sets that are critical for assessing impacts of the environment and provide early warning information. This list was refined with the time and as the database was built. Some of the global data sets have been relatively easy to obtain, such as NOAA AVHRR derived satellite data, Topographic data, Landsat Thematic Mapper (TM) satellite data and global population data, because their existence is widely known and there is an established, accessible distribution mechanism. Other data sets are more difficult to obtain because no clearinghouse or defined point of contact existed for information about the data. Generally, most organizations are cooperative within the limitations of their resources.

UNEP/GRID built its database for this project by 1) obtaining existing digital data, 2) converting existing data from one form to another; 3) automating data from paper documents or maps, 4) interpreting original source data to form analytic data sets, and 5) combining or analyzing existing data to form new data sets. Data were compiled from a number of sources, at a variety of scales, and in many formats that are designed for widely different purposes. The principal coverage and the ones that are close to final form are discussed here.

<u>Asian administrative boundaries and population datasets</u>

Developing Asian administrative boundaries and population databases is part of an ongoing effort to improve global, spatially referenced demographic data holdings. Such databases are useful for a variety of applications including strategic-level environmental assessment research and applications in the analysis of the human dimensions of global change.

While the private sector is addressing some of this need for spatial data by marketing georeferenced demographic databases for developed and some large developing countries (e.g., India), administrative boundaries and population figures for many countries are still hard to obtain. The project has pooled available data sets, many of which have been assembled for the global demography project. All data were checked, international boundaries and coastlines were replaced with a standard template, the attribute database was redesigned, and new, more reliable population estimates for sub-national units were produced for all countries. From the resulting data sets, raster surfaces representing population distribution and population density were created.

a. Discussion of data sources

The Asian administrative boundaries and population database was compiled from a large number of heterogeneous sources. The objective was to compile a comprehensive database from existing data in a fairly short time period that is suitable for regional or continental scale applications. The resources available did not allow for in-country data collection or collaboration with national census bureaus. With few exceptions, the data do not originate from the countries, and none of the input boundary data have been officially checked or endorsed by the national statistical agencies.

b. Population data

With few exceptions, official census figures or official estimates were used, taken from national publications (census reports or statistical yearbooks) or from secondary data sources (yearbooks and gazetteers). The specific sources are indicated for each country below. The accuracy of censuses obviously varies by country. It was beyond the scope of this project to evaluate the accuracy of every census used, or of any of the official estimates. This would be possible since most censuses are followed by a post-census enumeration that provides an accuracy estimate. In countries with functioning registration systems, population figures reach accuracy within a fraction of a percent. In the US, census counts have been shown to have an accuracy of about 2 percent. With few exceptions, the accuracy of Asian censuses is likely to be considerably lower.

Since census is irregular in many countries, the data for some countries are quite old. For several nations data from the early 1980s is the only available source of subnational population figures. The following figure shows the distribution of reference years in the database. For about 25% of the countries, the reference year is 1988 or earlier. It is important to note that this distribution and the average year (1990) are biased upward by those countries for which no sub-national data were available, in which case the 1995 UN figures were used.

UN population figures were used in two additional cases: (1) for countries for which no sub-national boundaries or data are available (e.g., Singapore, Bahrain, Lebanon), the 1995 population estimate from the UN Population Division was used; (2) in countries for which census figures are available for only one point in time or for which the next to last census is too long ago, the average annual national growth rate between the census year and 1995 was applied to each administrative unit, as indicated in the UN

World Population Prospects, resulting in a uniform adjustment of population figures across the nation. In countries where large areas are uninhabitable, the mean resolution in km gives a biased impression of available detail. In such cases, the number of people per unit is a more meaningful indicator.

Land cover data set

The land cover database was derived from the IGBP land cover characteristics database developed through international cooperation with USGS EROS Data Center. Vegetation classifications and descriptions in the USGS land cover database are built on characteristics of vegetation seasonality determined in terms of 1992-93 NOAA AVHRR NDVI. In the database, unique NDVI signatures and associated attributes, such as terrain and eco-regions, characterize large-area land cover patterns. The magnitude of integrated NDVI over the length of the temporal period has helped to separate successively decreasing vegetation primary production, ranging from healthy, dense forestlands to open woodland, shrubs and grass, and sparse land cover. Additionally, seasonal variations were investigated to partially support identification of vegetation physiognomy (e.g., separating deciduous from evergreen forests). The use of both integrated NDVI and seasonal NDVI variations has been found helpful in applications such as monitoring large-area vegetation interannual variations (Reed et al. 1994) and mapping tropical deforestation and fragmentation (Skole and Tucker, 1993).

To provide the least atmospherically affected result, the final percent forest cover is determined over the course of the year on the basis of maximum monthly forest cover value achieved, regardless of the methods chosen (mixture analysis or scaled NDVI). Using the estimated forest density and information about the two methods, a simple modeling process is developed to guide decisions on adapting the mixed seasonal classes (in terms of the FAO forest classes) from the first step.

The modeling process determines the level of forest fragmentation if forest density is from the modified mixture analysis and separation of various types of forest and woodland from other land cover is based on results from the linear NDVI scaling. Because of varying ecological conditions within and between continents, flexible regional rules are developed according to reference data in determining forest density threshold values for the FAO forest classes.

Political Boundaries Data

Political Boundaries Data set for the country boundaries is the National Imagery and Mapping Agency's (NIMA) Vector Map Level 0 (VMAP0) series of CD-ROM. This data set provides, among other things, a 1995 version of the political boundaries of the world at 1:1,000,000 nominal scale. The political boundaries layers for this data set is stored using the Geographic coordinate reference system, and is divided into 4 regional CD-ROM. The input layers were read from the CD-ROM set in its VPF format using ArcVIEW. These data have been converted to ARC Shape files and then brought into ArcINFO for further editing. The Shape files have been converted to ArcINFO REGIONs regions, and into POLYGON coverages. The data are compared to the NIMA Digital Chart of the World (DCW) data set and found to be in error in several places. DCW linework was added to the VMAP0 data wherever it was found to be appropriate to correct and complete the VMAP0 data.

Attribute assignments have been verified and corrected as needed for the resulting polygon coverages, and the coverages have been joined to form world coverage. The world coverage was intersected with a polygon coverage denoting the 12 Goode's regions and 2 cap regions. (Note that regions here are Goode's regions, not ArcINFO REGIONS). Geographic areas in the 2 cap regions have been replicated and moved to extend beyond +/- 180 degrees, allowing for repetition of the features found in the cap regions. Attributes have been then assigned to the resulting regions. Each land area is represented by a numeric code for the country that it belongs. Disputed regions, regions of special administrative status, foreign holdings, and regions that appeared in the caps have been assigned incremented codes offset from the base numeric code for the country, allowing varying interpretations in defining statistics for a country.

The features for each Goode's region have been projected to the Goode's component map projection for that region, and the data have been joined in the Goode's coordinate space. Countries have been aggregated from the polygon components, and the resulting political layer has been rasterized at 1 km resolution.

Global Protected Areas

The world's protected areas are the greatest legacy that can be left to future generations - to ensure that future descendants have access to nature and all the material and spiritual wealth that it represents. IUCN – the World Conservation Union, defines a protected area as: "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other affective means."

IUCN categorizes protected areas by management objective and has identified six distinct categories of protected areas:

- Strict Nature Reserve/Wilderness Area: protected area managed mainly for science of wilderness protection.
- National Park: protected area managed mainly for ecosystem protection and recreation.
- Natural Monument: protected area managed mainly for conservation of specific natural features.
- Habitat/Species Management Area: protected area managed mainly for conservation through management intervention.
- Protected Landscape/Seascape: protected area managed mainly for landscape/seascape protection and recreation.
- Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems.

Until the year 2000, the world's 30,000 protected areas covered over 13,250,000 km^2 of the land surface of the world (roughly the size of India and China combined). A much smaller proportion of the world's seas (barely 1%) are protected. This represents a tremendous investment by the countries of the world to protect their biological diversity for future generations.

Protected areas perform many functions. They are essential for conserving biodiversity, and for delivering vital ecosystem services, such as protecting watersheds and soils and shielding human communities from natural disasters. Many protected areas are important to local communities, especially indigenous peoples who depend for their survival on a sustainable supply of resources from them. They are places for people to get a sense of peace in a busy world - places that invigorate human spirits and challenge the senses.

Protected landscapes embody important cultural values; some of them reflect sustainable land use practices. They are important also for research and education, and contribute significantly to local and regional economies, most obviously from tourism. The importance of protected areas is recognized in the Convention on Biological Diversity (CBD). Article 8, for example, calls on contracting parties to develop systems of protected areas.

Protected areas face many challenges, such as external threats associated with pollution and climate change, irresponsible tourism, infrastructure development and ever-increasing demands for land and water resources. Moreover, many protected areas lack political support and have inadequate financial and other resources.

There is only one body working world wide for the protection of these vitally important areas. This is the World Commission on Protected Areas (WCPA) - one of the six Commissions of the IUCN.

The protected areas database is extracted from the 1997 CD-ROM title “A Global Overview of Forest Conservation” published by the UNEP- World Conservation Monitoring Center (WCMC)).

Global 30 Arc-Second Elevation Data Set

GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 is derived from several raster and vector sources of topographic information. For easier distribution, GTOPO30 has been divided into tiles that can be selected from the map shown above. Detailed information on the characteristics of GTOPO30 including the data distribution format, the data sources, production methods, accuracy, and hints for users, is found in the GTOPO30 README file. GTOPO30, completed in late 1996, was developed over a three-year period through a collaborative effort led by staff at the USGS EROS Data Center (EDC). Numerous organizations participated by contributing funding or source data: the National Aeronautics and Space Administration (NASA), the United Nation Environment Programme/Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadistica Geografica e Informatica (INEGI) of Mexico, the Geographical Survey Institute (GSI) of Japan, Manaaki Whenua Landcare Research of New Zealand, and the Scientific Committee on Antarctic Research (SCAR).

Fig. 7.2-1 Flood in Bangladesh. (*'Asian people in Britain are desperate to do what they can for the 30 million Bangladeshis whose lives have been torn apart by the worst floods in living memory.'* Aziz-Ur Rahman, Vice-Chair of the Guild of Bangladeshi Restaurateurs. Source: Oxfam, 1998).

FAO global soil data set

The FEWS Flood Model requires data describing the average water holding capacity of the soils in millimeters, average hydrologic active soil depth in centimeters, textural description of the soil, average saturation soil hydraulic conductivity in meters per hour, average Soil Conservation Service curve numbers for the soils, maximum percentage of the watershed which can be impervious, and minimum percentage which can be impervious for each sub watershed that makes up the watershed being modeled. The FAO soils database at 1:5 million scale contains a great deal of information about the soils of the world.

Climate Data

Historical data on monthly temperature, precipitation, and evaporation for national climate divisions throughout the area can be obtained from the government or local climate Centers.

8 Assessing human vulnerability due to floods in two basins

8.1 Introduction

The Ganges/Brahmaputra and Yangtze River basins in Bangladesh, China and India are two of the most densely populated basins in the world with 1.6 billion people.

Approximately 40% of the total population of the three countries lives along the river and coastal areas. They are extremely dependent on natural resources such as water, woods as fuel, fruits, large fish resources, etc. The people living in these regions of the two basins are most vulnerable to natural hazards such as cyclones and floods. The occurrence of floods in these areas is very frequent. Floods take million of lives and property and cause loss of natural resources in these and adjoining areas. For example, in spite of flood warning systems, a recent cyclone with resulting flooding killed about 10,000 people and millions of people became homeless. These two basins, in general, are two of the most vulnerable regions in the world in terms of floods. Figure 8.1 shows the development of a cyclone close to east coast of India and it will cause a flood. In Orissa, during the last cyclone with subsequent flooding, 90-100 % of agricultural crops were damaged in vulnerable areas as the flood hit at the most vulnerable time for the paddy crop.

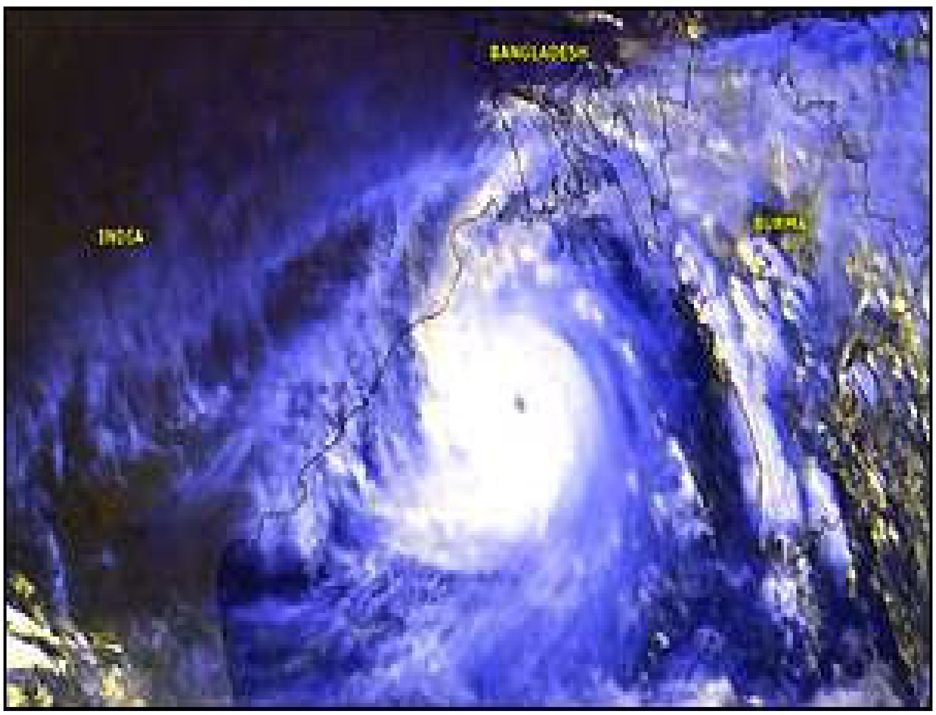


Fig. 8.1-1 Tropical Cyclone close to east coast of India (NOAA, 1998)

Vulnerability studies of the two basins due to flooding have been made. The vulnerability of the region is modeled and population is calculated through GIS in terms of people density and flood risk.

8.2 Key factors that affect people and the environment

Human beings have a close relationship with their environment. The relationships are inter-dependent. While human activities modify, shape, and affect the environmental processes, the processes also affect human activities. The total impact of environmental modifications causes damages to humans as well as to their living environments. The impact to humans depends on their exposure and coping capacity to a particular effect.

People in the study areas are exposed to risk due to a number of factors: population clustering and high population density; land cover change; poor quality of human health; poor access to transport, communication and other infrastructure, food deficit; geographical exposure and natural disasters are some of the factors. Further, fragile ecosystems such as diminishing grasslands, wetlands and forests face threats from environmental modifications, particularly when these ecosystems have to compete with humans for their existence.

People and their ecosystems in the study areas are more exposed to the effects of environmental changes. Concentrations of people and cities demand more services and land resources. Intense human activities degrade the quality of the environment – air, land, and water. Even though there are a number of causes that indicate why people and their ecosystems are vulnerable to certain risks, only the key factors have been considered in this study due to lack of reliable data. In this report, population, land cover, protected areas, biodiversity hot spots, and exposure to flood and storm surges have been examined as the key factors in assessing the status of environments.

Fig. 8.2-1 Flood in China (Source, CNN, 1998)

8.2.1 Main disaster — flood

As discussed above, flooding is the main disaster in these two basins. Every year during the monsoon season catastrophic floods on the plains of the Ganges/Brahmaputra and Yangtze Rivers occur. It is generally assumed that forest cutting in the upstream areas is responsible for the apparent increase of floods in the lowlands and downstream (Farzend, 1987). Population growth in the upstream areas increases the demand for fuel wood, fodder and timber; uncontrolled and increasing forest removal in more and more marginal areas; intensifies erosion and higher peak flows in the rivers, contributing to severe flooding in the densely populated and cultivated plains of these two basins. On one hand, there is no doubt that upstream areas and forest lands have undergone a most dynamic change in land use in recent decades due to rapid increase in population; flood hazards are aggravated by human activities. On the other hand, human vulnerability is increased because of high population density in big cities and more developed economics. Several photos and images of floods in Bangladesh, China and India are shown in Figs. 8.2-1,2 (a, b, c).

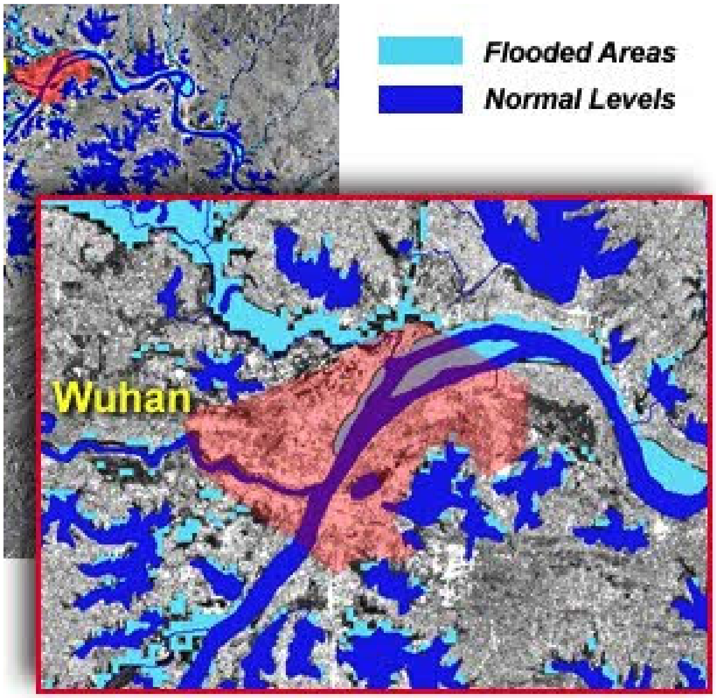


Fig. 8.2-2 (a) Image of flood in Yangtze River basin. RADARSAT Tracks Yangtze River flooding in China Aug 12, 1998 (Source: RSI, 1998)

Fig. 8.2-2 (b) A Life boat during a flood in Bangladesh (Source: CNN, 1998)

Fig. 8.2-2 (c) A week after the flood these villages off the Cuttack Paradeep expressway remain marooned. India (Source, UNICEF, 2001)

8.2.2 Population concentration

A considerable portion of the study areas is among the most crowded regions in the three countries. There is no reliable basin estimate as to how many people live in the two basins. This disparity is mainly related to lack of consistent and uniform methods of assessing population distribution in two basins. This is a first study that attempts to provide basin-wise estimations of total population as well as their spatial distributions.

Fig. 8.2-3 Over two million people have to get home after a religious festival! Why not take the train? No, not all at once! Scenes like this are a photographer's paradise. Make sure you find a suitable spot. Have all your gear ready and then shoot to your heart's content. If anything goes wrong, there's always another chance at next year's festival (Source: Dirk R. Frans, 2001)

Fig. 8.2-4 Much of the high human loss that occurs during natural disasters happen because of high population density. The photo above shows a crowded fish marketplace in India (Source: FAO Image/ G. Bizzari)

8.2.3 Land cover change

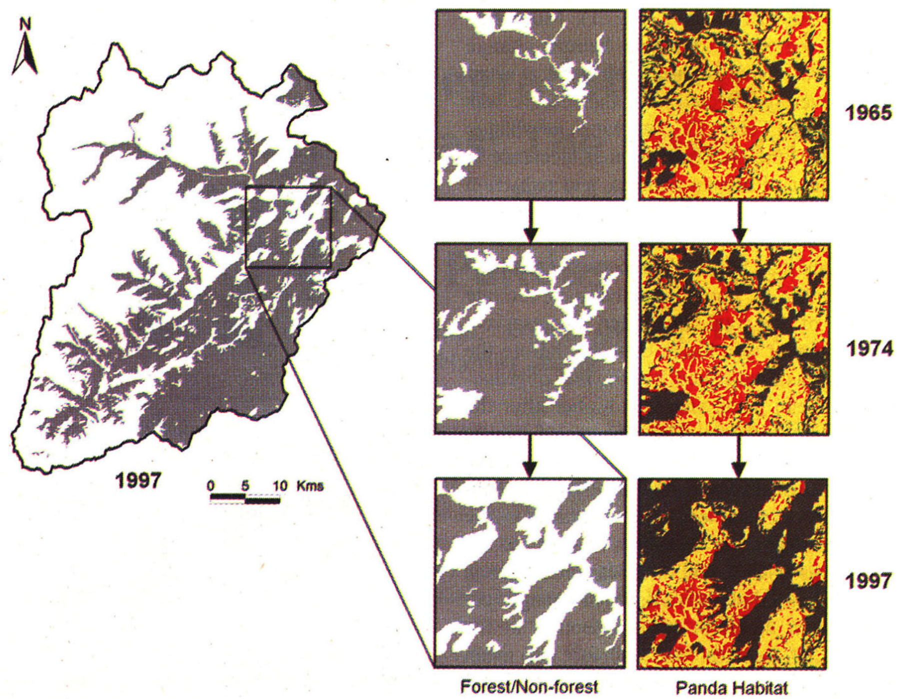


Fig. 8.2-5 Land cover change: Degradation in protected areas: the case of Wolong nature reserve located at upstream of Yangtze River, China (Source: Science, 2001)

High population growth and urbanization demand increased food production and more resource use. In the study areas, land is limited and competition for resource use is high due to increasing urbanization and agricultural expansion. The impact can be seen through the depletion of biodiversity, soil erosion, and deforestation and wetlands disappearance. The study areas, habitats, and land resources are vital to the communities and to the economic success of the countries. Sustainable management requires regular assessment of the distribution and patterns of land resources. Degradation of land resources exposes the communities and ecosystems to flood hazard risk. A recent article in the 6 April, 2001 Science Journal revealed that even in the Wolong natural reserve, established to protect the home of the famed and endangered giant pandas, habitat degradation continues. The study analyzed data acquired over a thirty-year period and concluded that rates of degradation in the protected habitat were equal to areas outside the protected area. The rate of habitat degradation conclusively accelerated after designation of preserve in 1975 (Fig. 8.2-5).

8.3 Methodology

Data was processed using several remote sensing and GIS software systems (ERDAS, ESRI, 2000). Most of the work has been carried out in the GRID module of ArcINFO. Raster and vector data layers have been in an Interrupted Goode Homolosine Projection, which is an equal area projection. All raster data sets have a cell size of 1000 meters (1 km).

The data layers have been analyzed individually or combined with other data layers in order to see possible interrelations or possible spatial relationships among them.

For example, “basin layer,” “population density layer” and “political boundaries layer” have been digitally overlain in order to assess the population pressure on the two basins with three countries.

Population distribution was measured using a grid of political boundaries of the two basins. These layers are combined with the population grid data individually. The number of people from Bangladesh, India and China were counted for the two basins with the resulting data being exported as a spreadsheet and combined in one graph showing the population of the two basins.

8.3.1 Population density: The following classification was used for population density

- Low population density: < 25 people km^{-2}
- Medium population density: 25-100 people km^{-2}
- High population density: > 100 people km^{-2}

8.3.2 Land cover distribution

The land cover distribution in the two basins has been estimated by combining the land cover distribution grid with the two basins’ boundary grid individually.

8.3.3 Designated protection status

The protection status has been estimated by combining the protected area grid with the two basins boundary grids individually.

8.3.4 Biodiversity hotspots

The presence of biodiversity hotspots in two basins has been estimated by combining the hotspots grid with the two basins boundary grids individually.

8.4 An assessment of environment in two basins

8.4.1 Population distribution

China and India holds the largest population in the world, and Bangladesh has the highest human population pressure in the world. The population in three countries has increased from 954 million to 2,411 million in the last 50 years (WRI, 2001). In many parts of three countries, the two basins are among the fastest population growth areas (Beckel, 1998, Engelman, et al., 2000). Future environmental change, especially flooding, and disease are likely to affect the two basins within the three countries more than any other inhabited regions in the country. These regions contain approximately 55% of population in both of Bangladesh and India and 41% of China's population. The two basins are under increasing pressure from population growth and related development. The basic question is how many people live in these areas and what is their distribution? Different scientists have carried out work in these areas using statistical data. But there is no reliable estimate of how many people live in the two basins using consistent data sources and methodology. There exist multi-year statistical data by different level administration units in Bangladesh, China and India, but there is no clue as to how many people lives within the two basins. Hence, a reliable estimate of population distribution in the two basins is needed to reduce uncertainty.

Region	High population pressure	Medium population pressure	Low population pressure
Ganges/ Brahmaputra River basin	60.2	10.2	29.2
Yangtze River basin	60	14.2	25.8
Bangladesh	92.3	5.6	2.1
China	30.8	14	55.2
India	75	14.5	10.5

Table 8.4-1 Distribution of population pressure in two basins in three countries (Unit: percent of land area)

Based on this analysis, we can estimate that the two basins occupy approximately 41.9% of the land area in both of India and Bangladesh, and 20% of the land area in China. The comparison of population density in these two basins and the average in three countries provides that population density is higher in the two basins than total land, where there are on average 509 people/km^{-2} in the Yangtze Basin, 999 people in the Ganges basin in comparison to 137 people/km^{-2} in China and 367 in India and Bangladesh national average in 2000. In regards to population distribution in the two basins, 29.2% of the area has a low or non-existent population density, 10.2% has medium population density, and the remaining 60.2% is under high population pressure in the Ganges basin; 25.8% of the area has a low or non-existent population density, 14.2% has medium population density, and the remaining 60% is under high population pressure in the Yangtze basin (Table 8.4-1).

About 500 million people or 50% of the population in India and Bangladesh, and about 300 million people or 25% of population of China, live within these two basins.

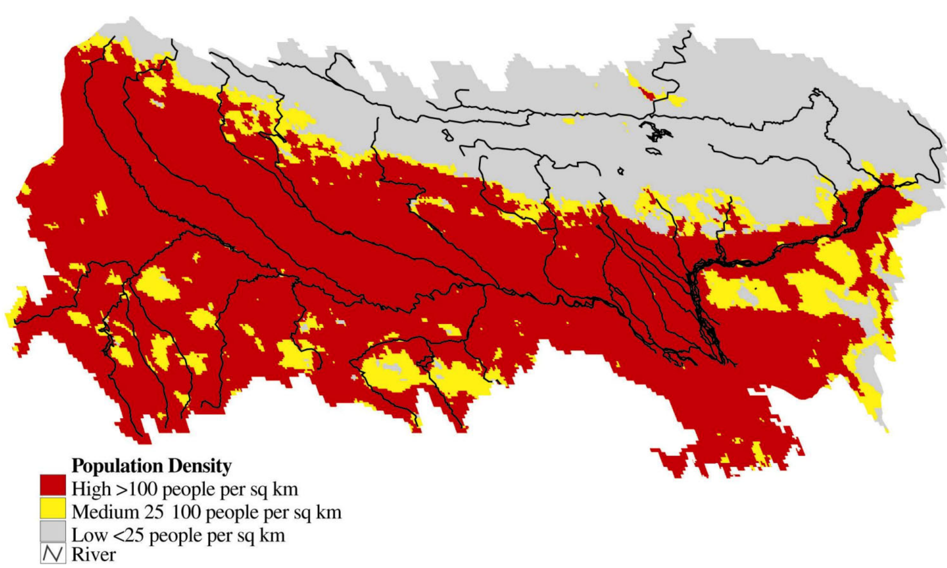


Fig. 8.4-1 (a) Population density in Ganges/Brahmaputra

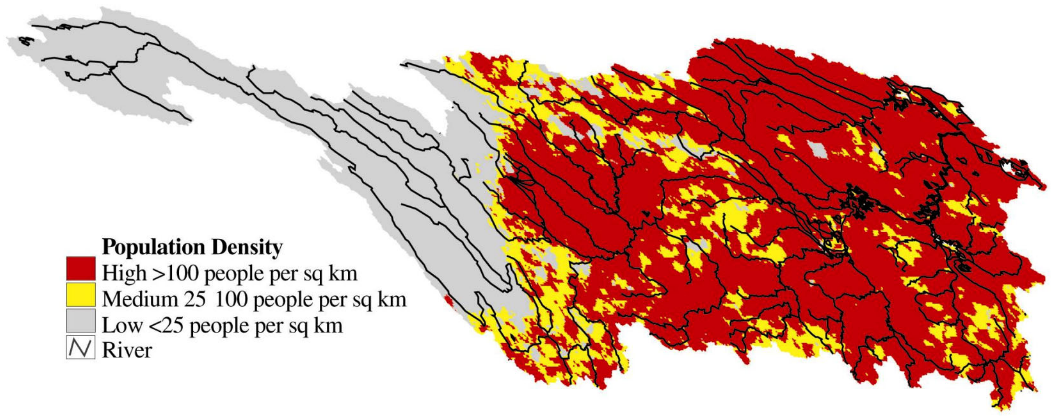


Fig. 8.4-1 (b) Population density of Yangtze basin

8.4.2 Distribution and pattern of land cover

In general, land resources everywhere are threatened by uncontrolled degradation and conversion to alternative land uses, including agricultural expansion, transportation and urbanization. The impact of loss and degradation can be seen through the depletion of biodiversity, desertification, deforestation, soil erosion, wetland disappearance, and economic development.

Diverse land resources and productive habitats are important for human settlement, development, and local subsistence. Despite efforts at varying levels, current approaches to the management of land resources have not always proved capable of achieving sustainable development while land resources and environment are rapidly being degraded and eroded. Rapidly growing developing countries usually base their economic success on the export of labor-intensive manufactured products. One of the greatest areas of economic success in the three countries has been in the export of these high labor products. The Ganges/Brahmaputra basin of India and Bangladesh, and the Yangtze basin of China will be the most threatened for development in order to gain access to markets if this trend continues. Sustainable development practices must be undertaken to ensure the vitality of the basins, and certain protection status must be provided to avoid excessive industrial development. Exploitation of natural resources will continue at an accelerated pace, while resources and environmental protection will also need to be addressed. Meanwhile, there exist many ecological and environmental problems such as water shortages, land degradation and heavy potential pressures from population growth and resources exploitation. In order to develop a suitable strategy for sustainable development of the basins, it is vital to assess the distribution and pattern of land cover and its protected status.

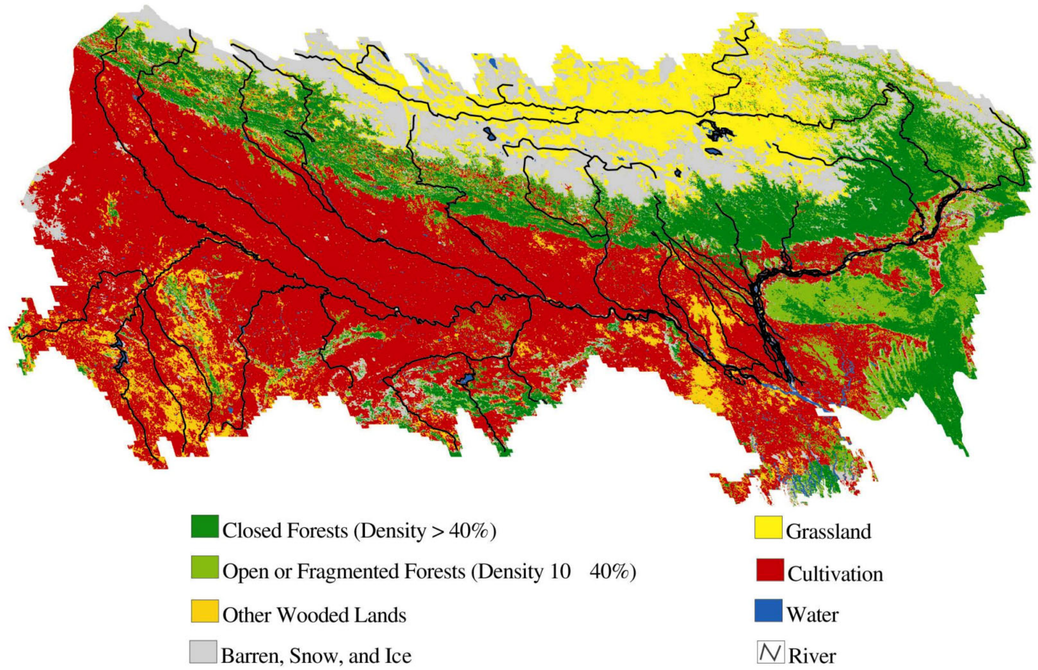


Fig. 8.4-2 (a) Land cover distribution of Ganges/Brahmaputra basin

This is the most comprehensive estimation of the distribution and pattern of land cover in the two basins using recent satellite data.

Land cover distribution in the two basins is derived from remote sensing data, and has the following distribution (Fig. 8.4-2 (a) and (b)): 1) Ganges/Brahmaputra basin: 15.4% closed forest (density >40%), 10.2% open or fragmented forests (Density 10-40%), 4.5% other wooded land, 13.4% barren, snow and ice, 10.3% grassland, 44.5% cultivation and 1.7% water. About 6.5% of the land has been accorded some sort of formal protection; 2) Yangtze basin: 16.6% closed forest (density >40%), 18.1% open or fragmented forests (density 10-40%), 10.1% other wooded land, 4.7% barren, snow and ice, 13.4% grassland, 35.4% cultivation and 1.7% water. About 7.8% of the land has been accorded some sort of formal protection (Table 8.4-2).

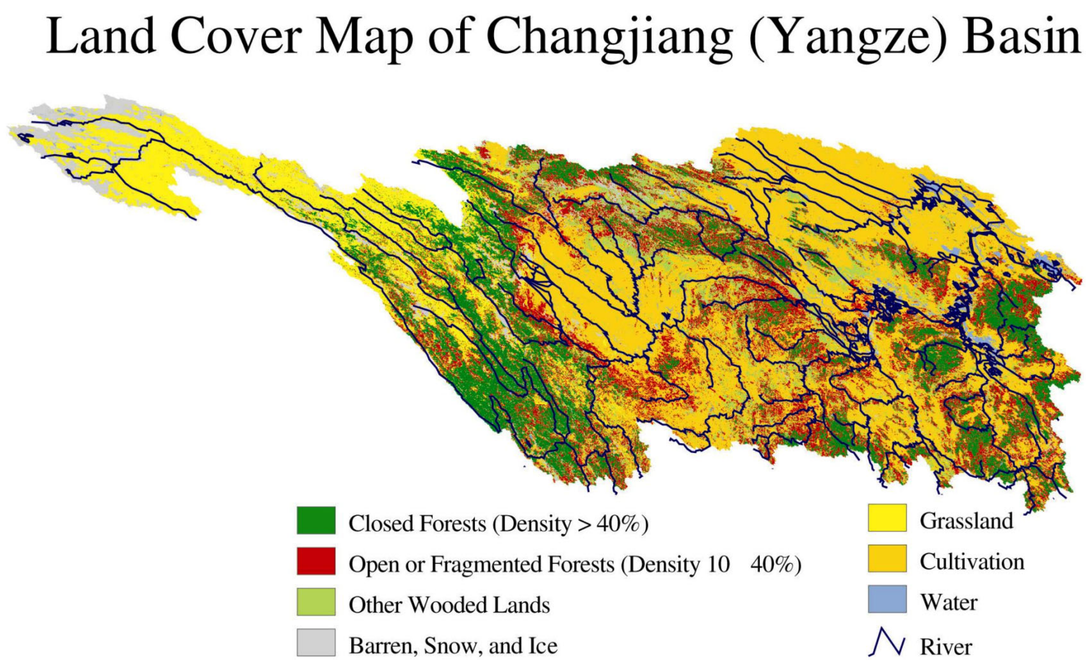


Fig. 8.4-2 (b) Land cover distribution of Yangtze basin

Land cover	Ganges/ Brahmaputra	Yangtze	Bangladesh	China	India
Closed forest	15.4	16.6	8.2	11.9	12.0
Open and fragmented forest	10.2	18.1	19.8	10.6	8.6
Other woodland	4.5	10.1	6.2	3.8	9.2
Barren, ice and Snow	13.4	4.7	4.0	33.7	16.2
Grassland	10.3	13.4	0.5	17.1	0.6
Cultivation	44.5	35.4	56.2	21.7	52.3
Water	1.7	1.7	5.2	1.2	1.1
% of protected land	6.5	7.8	7	5.6	4.5

Table 8.4-2 Land cover distribution with protection status (percent of land area)

In Fig.8.4-2, land cover patterns of the two basins are apparent. Several broad areas of forested land cover can be seen in the northeast, southeast, and southwest with barren/ice and snow cover existing in the extreme northwest and Tibet regions. Cultivated land is primarily located in the eastern part of China. Most grassland can be seen in the northern region and Tibet. The western region has 7.8% of land area designated as being protected, which is higher than the national average.

8.4.3 Status of designated protected areas and bio-diversity hotspots

Biodiversity, the variety and variability among living organisms and the environment in which they occur, is important to maintain life-sustaining systems of the biosphere (Myers, 1988). Many human activities are reducing overall biodiversity. The total number of species that inhabit the planet is unknown and it is feared that the extinction of many will occur even before they have been named and described. It is estimated that 85-90% of all species can be saved by identifying and protecting areas of high biodiversity before they are further degraded, without having to actually inventory species individually (Myers, 1990). Realistically, only a relatively small portion of total land areas are likely to be devoted to biodiversity conservation; hence, it is important to identify areas rich in species diversity and endemism for priority-setting purposes. In the past, areas have been set aside as protected, often without regard to the biodiversity within their boundaries. As a result, many designated protected areas have little significance in terms of biodiversity, and conversely, many areas of habitat with significant biodiversity lack protection.

The next half-century could be called the “last chance decades” (Mittermeier et al., 1999). These could be some of the most dangerous years ever for the Earth’s species and ecosystems. Yet this is also a time in which we will still have a chance to make a difference. There remains a relative handful of fragile places where biodiversity is still robust. These biodiversity “hotspots” are remote, they are spectacular – and, without expectation, they are in danger of being destroyed. To protect the diversity of life on the Earth, we need to protect these valuable hotspots (Myers 1990). Bangladesh, China and India have a very rich biodiversity, and China and India are two of only 12 “mega diversity countries” in the world (McNeely et al. 1990). The Yangtze basin in China has some of the world’s most interesting and best known flagship species, of which the giant panda, perhaps the world’s number one wildlife symbol, is the most famous. In the three countries, every bit of available land is occupied by and under the influence of humans, even in areas above the timberline. All biodiversity hotspots and protected areas in the three countries are not exempt from this influence. In order to address the issue, this study has been designed to assess and analyze the status of protected areas and biodiversity hotspots in the two basins within the three countries to answer the question: Are areas in hotspots with significant biodiversity in the two basins adequately protected?

Designated protected areas in the Ganges/Brahmaputra basin occupy roughly 2.8% of the land area. About 3.6% closed forests, 3% open and fragmented forests, 3.9% other woodland, 9.6% barren, snow and ice, 8.5% grassland, 1.8% cultivation and 1.2% water has been designated as protected areas in the land area. Designated protected areas in the Yangtze basin occupy roughly 7.8% of the land area. About 2.7% closed forests, 3% open and fragmented forests, 2.7 % other woodland, 11.7% barren, snow and ice, 1.9% grassland, 1.3% cultivation and 22.2% water has been designated as protected areas in the Yangtze basin. Forests, especially tropical and sub-tropical forests, are biologically the most diverse and home to thousands of endemic species.

Worldwide, approximately 3.4% of the area within biodiversity hotspots is concentrated in these two basins. The regions include 29.8% of the Ganges/Brahmaputra basin, and 15.1% of the Yangtze basin. Both of these regions are “bright hot” in progress of economic development in these three countries, while at the same time being “hotspots" for biodiversity.

Of the 25 total hotspots around the world, 2 are at least partially within the Yangtze basin. The mountains of south central China are mostly located in the Yangtze basin; part of the Indo-Burma hotspot lies within the Yangtze basin. The Indo-Burma hotspots are largely located in the Ganges/Brahmaputra basin.

Population pressure is high in the portions of these two hotspots that lie in the two basins. About 26.6 million people live in and around the Indo-Burma hotspot; 62.3% of the hotspot area has a high-population density, 27.7% has medium-population density and only 10% is considered low-population density. About 10.9 million people live in and around the mountains of the south central China hotspot. About 5% of that area has a high-population density, 11.3% has medium-population density, and 83.7% has low-population density.

The lack of designated protected areas within Bangladesh, China and India is alarming. On an average, only 5.6% of the total land area of two basins, and only 4.2% of hotspots in the two basins, 3.5% of hotspots in the Ganges/Brahmaputra basin, and 3.1% of hotspots in the Yangtze basin are designated as protected areas. Only 3% of the land area within the mountains of the south central China hotspot holds any type of protected status, and the hotspot of Indo-Burma has only 5.4% of the total land of the two basins under designated protected status. The critical issue is to establish immediate protection status in areas that remain unprotected.

8.4.4 Surface topographic characteristics

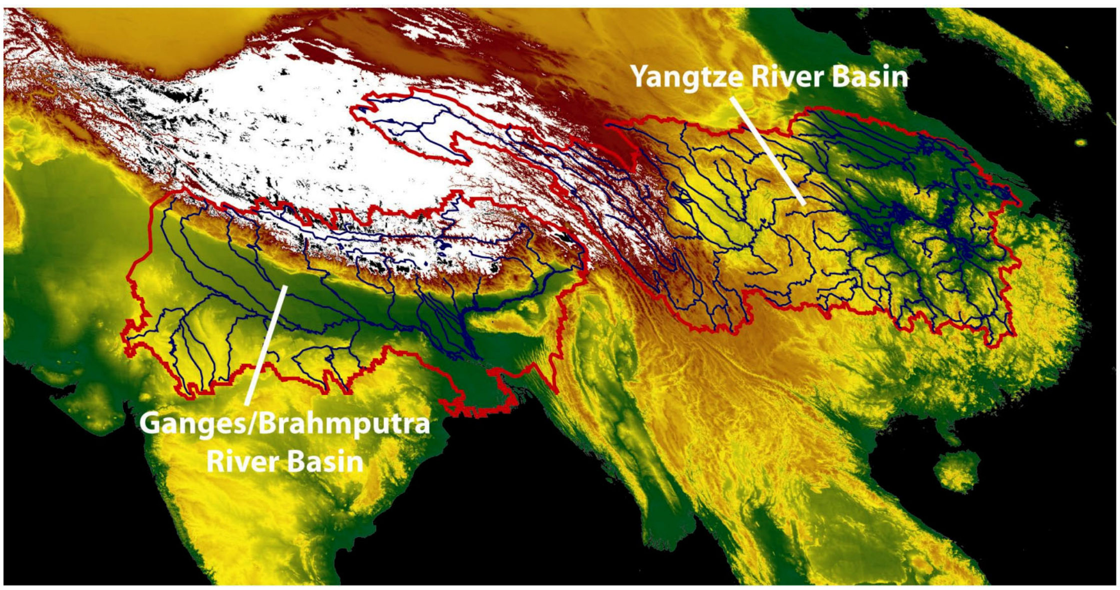


Fig. 8.4-3 A DEM model map of Ganges/Brahamputra River and Yangtze River basins

Many parts of the two basins, particularly in downstream rivers, have a majority of their land characterized as relatively flat (elevation under 50 m). For instance, the Bengal delta in Bangladesh and the delta of the Yangtze have more than 90% and 70% of their land under 50 m elevations, respectively. People and ecosystems in low elevation areas (coastal areas) are more exposed to floods (coastal floods due to wind storm and tidal wave actions) compared to high elevation areas (Fig. 8.4-3).

8.5 Vulnerability due to floods

Human vulnerability can be defined as the exposure to hazards by external activity (e.g. the climatic change) and coping capacity of the people to reduce the risk. In other words, vulnerability is the function of exposure to hazard and coping capacity at a certain point of time. Vulnerability is also connected with access to opportunities, which defines the ability of people to deal with the impacts of the hazard to which they are exposed. It states the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact.

Fig. 8.5-1 People try to collect pure drinking water that was scarce during the flood in Bangladesh. (Source: Daily Tttefaq, 1998)

The vulnerability analysis for the project has two major parts: a human component and an environmental component. The human component is the most important part as if there is no human activity; there is no human vulnerability. Global population and resources are unequally distributed over the earth surface. The largest concentration of population and resources are found in the Ganges/Brahmaputra and

Yangtze basins. These two basins have extensively been used for human activities – city development, agriculture, and resource exploitation. The basins also house pristine habitats such as wetlands and areas for unique wild life. Extensive use of the two basins for human activity has led to conflicts between resource use and environmental quality on these areas. This is the human dimension of the problem.

The environmental component is the other dimension of vulnerability. Whether natural or man-made, environmental changes have a significant impact on people as well as on overall ecosystems of the two basins. Impacts of climate change on the environment have received wide attention among the research community. This is mainly related to recent advances in spatial information technologies, which show that physical changes in the environment, increasing storm activity, flood and unusual weather patterns have some links to global climate change.

Human impact on the environment increases environmental vulnerability, which also increases human awareness and stimulates human efforts to protect the environment. It is hoped that increased human awareness will decrease future human impacts.

Fig. 8.5-2 The house remains submerged a week after the first flooding in India (Source, UNICEF, 2001)

9 Conclusions and main findings

Large river floodplains around the world support heavy population settlements where most often, development goals are improved navigation, enhanced agricultural production and flood protection. Floods are one of the most common devastating natural hazards in the world, claiming more lives and property when compared to other natural disasters. Floods are frequent and a common feature every year especially after heavy rains or thunderstorms, winter snow thaws, strong cyclones and monsoons. Floods can be slow or fast rising depending upon the amount of rains and snow melt, and generally develop over a period of days. Floods have also created havoc and loss of life and property instantaneously after dam failures. Potentially the worst flood events are due to poor dam design and/or structural damage caused by a major event such as an earthquake.

Eliminating the “flood problem” in Bangladesh is nearly impossible. Improved understanding of the causes of flooding, better forecasting, monitoring and early warning of flood events and more sophisticated responses to the flood hazard will, in the long term and on a year-to-year basis, reduce the enormous damage and loss of life to which many have become accustomed. Densely populated floodplains and coastal lowlands will eventually experience a more catastrophic flood, perhaps in the form of a 1000-year flood, a 2000-year flood or even the Probable Maximum Flood. When that happens flood defenses will be overtopped with the direst of consequences (Smith and Ward, 1998).

Through a review of early warning and flood forecasting tools and models being used by developed countries, this study attempts to assess the gap in knowledge and technology being deployed by developing countries. It is hoped this will assist in knowledge transfer related to operational systems for flood risk monitoring using the latest tools and technologies.

Improved databases are likely to play an important part in Bangladesh, China and India. Relevant databases on numerous parameters using GIS for the two river basins have been compiled and analyzed to demonstrate the usefulness of GIS to visualize the early warning of floods, occurrence of floods and total affected areas.

A reliable assessment of the current status of the environment in the two basins is long overdue. The major constraint has been the lack of accurate and timely data at the basin level. Recent advances in spatial data gathering and processing techniques such as satellite remote sensing and GIS have helped the research community address these issues. It is vital to assess human vulnerability to environmental threats in these two basins using population distribution, land cover, topographical characteristics of the landscape, potential of flood occurrence and the strength of people’s coping capacity.

People in these areas are relatively more exposed to environmental threats. This study shows that the vulnerability of a community to environmental threats depends on their exposure and coping capacities. These two basins with high population concentrations and a high probability of natural disasters (floods) are highly vulnerable.

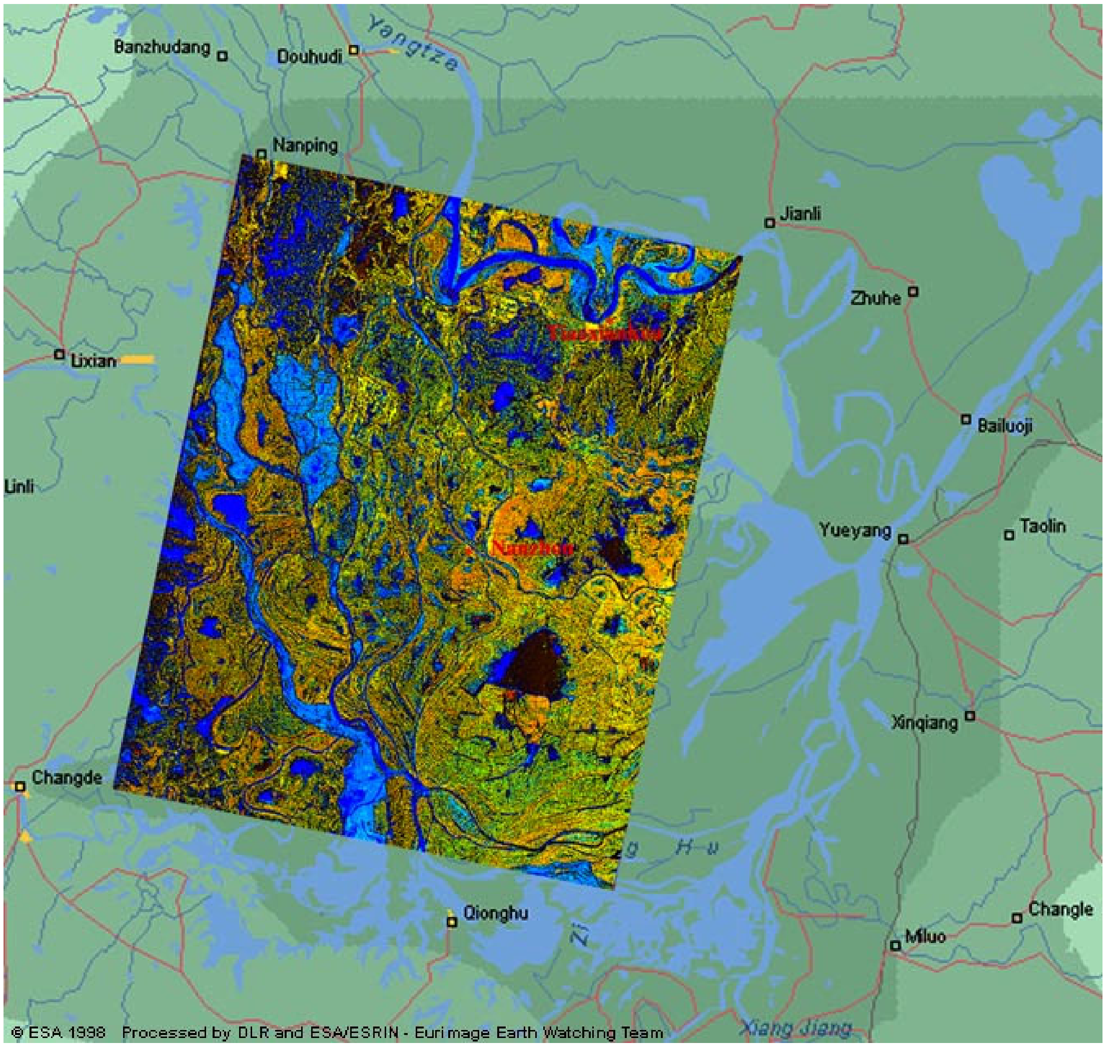


Fig. 9.0-1 Yangtze River Flood (July-August 1998). The image shows an area located about 200 km southwest of Wuhan, one of the cities most damaged by the floods along the Yangtze River in China. The image was obtained by geocoding and superimposing an ERS SAR multitemporal data set (processed by DLR) onto a topographic map of the area. The ERS data used for the multitemporal image have been acquired by Ulan Bator ground station on 9/6/1993 (reference frame) and 1/8/1998 (during the flood event). Flooded zones are shown in light blue tones. Areas normally covered by water such as lakes, artificial basins and swamps are visible in dark blue or black colors. See also comments on the disaster and same SAR image before and after superimposition (August 1st, 1998 - June 9th, 1993). (Copyright © Eurimage – Earthwatching, Source: ESA, 2002)

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Acronyms and Abbreviations

AFP	France-Press
AVHRR	Advanced Very High Resolution Radiometer
CI	Conservation International
CLIFF	Cluster Initiative for Flood and Fire emergencies
CNIE	Committee for the National Institute for the Environment
CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
EDC	EROS Data Center
EFFS	The European Flood Forecasting System
ENVI	The Environment for Visualization Images
EPA	U.S. Environmental Protection Agency
EROS	Earth Resources Observation Systems
ERS	Earth Resources Satellite
ESA	Earth Observation Applications
ESRI	Environmental Systems Research Institute, Inc.
EVI	Economic Vulnerability Index
FEWS	The Famine Early Warning System
FAO	Food and Agricultural Organization of the United Nations
FFWC	Flood Forecasting and Warning Centre
FHI	Food for the Hungry International
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIEWS	Global Information and Early Warning System
GIS	Geographical Information Systems
GIWA	Global International Water Assessment
GLOBEC	Global Ocean Ecosystem Dynamics
GPA	Global Programme of Action
GOB	Government of Bangladesh
GPS	Global Positioning System
GRID	Global Resource Information Database
HDI	Human Development Index of UNDP
HEC	Hydrological Engineering Center (U.S. Corps of Engineers)
HYRAD	Hydrological Radar
IDNDR	International Decade for Natural Disaster Reduction
IFPRI	International Food Policy Research Institute
IGBP	International Geosphere-Biosphere Programme
IMO	International Meteorological Organization
IPCC	Intergovernmental Panel on Climate Change
IRF	Intermediate Regional Flood

IUCN	World Conservation Union
JGOFS	Joint Global Ocean Flux Study
LOICZ	Land – Ocean Interactions in the Coastal Zone
MRC	Munich Reinsurance Company
NAS	The National Academy of Sciences
NDVI	Normalized Difference Vegetation Index
NIMA	US National Imagery and Mapping Agency's
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service (USA)
OFDA/CRED	The Office of US Foreign Disaster Assistance/Center for Research on the Epidemiology of Disasters
PAGE	Pilot Analysis of Global Ecosystems
RSI	RADARSAT International
REF	Satellite Rainfalls Estimates
REFS	River Flow Forecasting System
SFHA	Special Flood Hazard Area
SOFIA	State of the World Fisheries and Aquaculture
SOPAC	South Pacific Applied Geoscience Commission
SST	Sea Surface Temperature
UN	United Nations
UNA	United Nations Association of Canada
UNDP	United Nations Development Programme
UNDRO	UN Disaster Relief Organization
UNEP	United Nations Environmental Programme
UNICEF	United Nations Children's Fund
USGS	United States Geological Survey
WCMC	World Conservation and Monitoring Center
WHYCOS	The World Hydrological Cycle Observing System
WMO	World Meteorological Organization
WRI	World Resources Institute